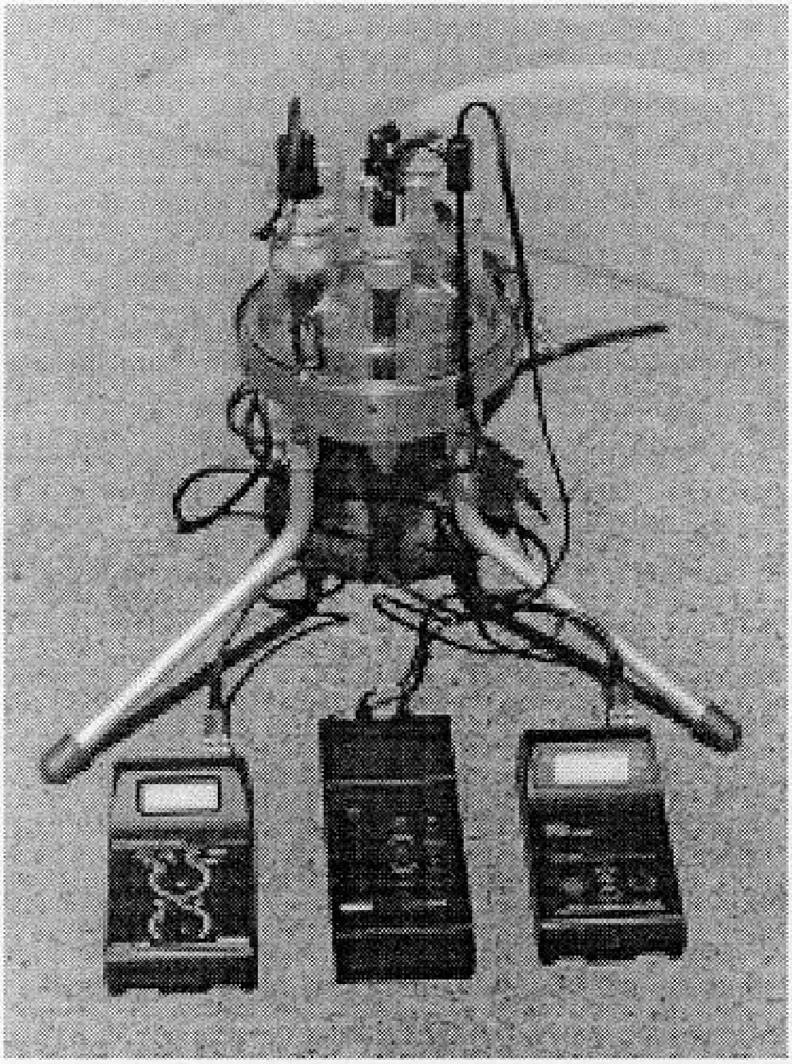
Groundwater Sampling Desk Reference



PUBL-DG-037 96
Produced by the Wisconsin Department of Natural Resources
Bureau of Drinking Water and Groundwater
September 1996

Groundwater Sampling Desk Reference

PUBL-DG-037 96

Produced by the Wisconsin Department of Natural Resources
Bureau of Drinking Water and Groundwater
September 1996

Author
Steve Karklins

Editor
Jordana Lenon

Cover design
Georgine Price

ACKNOWLEDGEMENTS

The author would like to express his sincere gratitude to the groundwater professionals who reviewed this document and the accompanying Field Manual in their draft forms. A special thanks is extended to the many reviewers with the Wisconsin Department of Natural Resources, Michael Barcelona with the National Center for Integrated Bioremediation Research and Development, along with technical staff from several environmental consulting firms including Northern Lakes Services, STS Consultants, Natural Resources Technology, John Robinson & Associates, RUST E&I, Dames & Moore, Montgomery Watson, and RMT.

DISCLAIMER

The mention of trade names or commercial products in this document does not constitute an endorsement or recommendation by the Wisconsin Department of Natural Resources. Also, while this document and the accompanying Field Manual include brief mention of health and safety issues, neither document adequately addresses all health and safety issues and requirements. Both documents should be supplemented with other appropriate references, requirements and training on health and safety.

ADDITIONAL COPIES

Additional copies of this document titled **Groundwater Sampling Desk Reference, Stock # 1728,** and the accompanying document titled **Groundwater Sampling Field Manual, Stock # 1729,** may be purchased from Wisconsin Department of Administration, Document Sales Unit. Call Document Sales at (608) 266-3358 or TTY (608) 264-8499 for pricing information (business hours 7:45 am to 4:30 pm).

Credit card orders using either VISA or MASTERCARD may be placed by calling the following numbers:

Long Distance:	1-800-362-7253
Local:	(608) 264-9419

Orders for the documents may be prepaid either with cash, money order, or check made payable to the Department of Administration and mailed to the following address:

Wisconsin Department of Administration
Document Sales Unit
202 South Thornton Avenue
P.O. Box 7840
Madison, WI 53707-7840

CONTENTS

GROUNDWATER SAMPLING DESK REFERENCE

TABLES

FIGURES

COMMONLY USED ACRONYMS

AA	Atomic absorption
ASTM	American Society for Testing and Materials
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CLP	Contract Laboratory Program
DNAPL	Dense Non-Aqueous Phase Liquid
DQO	Data quality objectives
DO	Dissolved oxygen
GC	Gas chromatogram
GC/MS	Gas chromatogram/mass spectrometry
gpm	gallons per minute
HSP	Health and safety plan
ICP	Inductively coupled plasma
LNAPL	Light Non-Aqueous Phase Liquid
mg/L	milligrams per liter
mv	millivolts
NTUs	Nephelometric turbidity units
POC	Purgeable organic compounds
PPE	Personal protective equipment
ppb	parts per billion
ppm	parts per million
PRP	Potentially responsible party
PTFE	Polytetrafluoroethylene, commonly available as Teflon®
PVC	Polyvinyl chloride
QA/QC	Quality Assurance/Quality Control
RCRA	Resource Conservation and Recovery Act
SAP	Sampling and analysis plan
SDWA	Safe Drinking Water Act
µg/L	micrograms per liter
µmhos/cm	micromhos per centimeters
VOCs	Volatile organic compounds
WDNR	Wisconsin Department of Natural Resources
WUWN	Wisconsin Unique Well Number

1.0 INTRODUCTION

1.1 PURPOSE AND USE

This desk reference can assist you with collecting data that represents in-situ, unaltered groundwater conditions. It emphasizes the importance of determining data objectives, developing and following site-specific sampling plans, making thorough pre-sampling preparations, following purging, sampling and quality assurance procedures consistently, and documenting the entire sampling event.

Included is a common reference of reliable purging and sampling techniques for a variety of groundwater contaminants and hydrogeologic conditions; however, the Wisconsin Department of Natural Resources (WDNR) recognizes that the recommended procedures may not suit all hydrogeologic and geochemical conditions and contaminants or parameters being collected or measured. Therefore, the WDNR will be flexible in allowing alternative procedures as long as they provide scientifically valid and legally defensible groundwater data.

This document and the accompanying *Groundwater Sampling Field Manual, PUBL-DG-038 96,* include a variety of procedural options for each task (e.g., purging and sampling monitoring wells). For each task, the first option consistently yields the highest level of data quality. Subsequent options may yield lower levels of data quality. A project's sampling plan should include specific procedures for collecting groundwater data.

1.2 GROUNDWATER QUALITY

Groundwater quality reflects the physical, chemical and biological processes and contaminants, whether natural or human caused, that transfer impurities to groundwater. Many human-caused contaminants can affect groundwater quality, such as hazardous spills, fertilizers, pesticides, leaking underground storage tanks and leaking landfills.

Shallow groundwater systems are particularly susceptible to impacts from certain land use practices (e.g., fertilizer and pesticide application), as well as seasonal variations in water quality and composition. Groundwater in shallow systems may also be oxygenated to some extent.

Deeper groundwater systems commonly have a high dissolved mineral content, due to long groundwater/mineral contact time. They also exhibit low dissolved oxygen, less seasonal variation in water quality and composition and are under greater hydraulic pressure than shallow groundwater systems. Deeper groundwater systems commonly contain one or more of the following naturally-occurring constituents: hardness, iron, radon, total dissolved solids, manganese, sulfate and radium.

Because of water's polar nature and hydrogen-bonding abilities, it acts as a nearly universal solvent; it dissolves and mixes with many organic and inorganic substances. A substance's water solubility is a good indication of the maximum concentration available for dissolution into groundwater. The actual chemical species of a compound or element dissolved in groundwater or attached to a solid's surface largely depends upon the solution's oxidizing-reducing status, the water's acid-base balance and the presence of complexing agents in the water. The following affect a chemical's transport and fate: 1) The nature of the mineral and the organic carbon content of aquifer materials (e.g., the organic content that affects a compound's retardation); 2) biological metabolic processes; 3) its precipitation or coprecipitation out of solution; and 4) the chemical's phase as it moves through an aquifer.

Groundwater may, or as is more likely the case, may not be in equilibrium with the aquifer materials and dissolved gases in the aquifer. The geochemical composition of groundwater typically reflects the geologic material it has flowed through and with which it has reacted (Summers and Gherini 1987).

1.3 COLLECTING PRELIMINARY SITE DATA

A common approach to assessing the degree and extent of groundwater contamination at a site is to install and sample a few monitoring wells. Several additional phases of well installation and sampling may also be required. By the time a project is completed, it is often apparent that some wells weren't necessary and that some wells should have been placed at different locations or screened at different depths.

Proper stratigraphic characterization of a site and the use of discrete-depth groundwater sampling can provide valuable preliminary information about subsurface hydrostratigraphy and the degree and extent of groundwater contamination. This information can prove invaluable for determining the appropriate number, location, screen length and depth of permanent monitoring wells and can save substantial time, money and sampling over a project's life.

1.3.1 Subsurface Stratigraphy

Hollow stem auger and split-spoon (i.e., split-barrel) samplers have been the norm for determining subsurface stratigraphy. Alternative methods may prove less costly and may be more effective under certain circumstances. Most of these alternative methods are described as direct push technologies (e.g., Geoprobe®, Diedrich®, Stratiprobe®, Precision®, etc.,) and can be used for soil sampling and subsurface stratigraphic profiling. Direct push technologies may also be used for soil vapor sampling and preliminary groundwater sampling. Common direct push technologies are hydraulic pushing systems, electric rotary-impact hammers, or hand-held slide hammers.

The main advantages of direct push methods over standard drilling methods (e.g., hollow stem augers) include: little or no generation of soil cuttings; faster soil sampling rate; lower cost; and equipment access into restricted clearance areas (e.g., inside buildings). The main disadvantages of direct push methods include: depth and soil type use limitations; smaller sample volumes; and the inability to collect certain types of soil samples. The sample tube opening of the direct push sampling tools is smaller and more restrictive than that of the standard split-barrel samplers. The presence of significant amounts of materials greater than one inch in diameter and the presence

of dry unconsolidated materials make sample recovery problematic for direct push sampling tools.

Cone penetrometers (another direct push method) are also gaining increased use and acceptance for characterizing site stratigraphy. A hydraulic ram pushes a mechanical or electronic cone penetrometer into the subsurface at approximately 4 feet per minute (1.2 meters per min). The penetrometer is commonly housed in a large truck specifically designed for cone penetration tests (CPTs) (**Figure 1**).

The basic electronic cone penetrometer used in CPTs consists of two separate soil shear resistance sensors – cone resistance and frictional resistance. These sensors acquire soil strength and stratigraphy data (refer to ASTM Method D-3441-86). Electronic cone penetrometers can also determine soil density, shear strength, and compressibility; and can relate resistance and friction to specific soil classifications (Ehrenzeller et al., 1991). Information obtained from CPT data can provide basic subsurface stratigraphic correlation and mapping data similar to that obtained from borings without human bias. Cone penetrometers can discern different soil types, aquifers and confining layers. If a pressure transducer is added to the electronic cone penetrometer, hydrostratigraphic information (e.g., soil saturation, water table, potentiometric surface and permeability in both aquifers and aquitards) can also be evaluated (Strutynsky and Sainey, 1992).

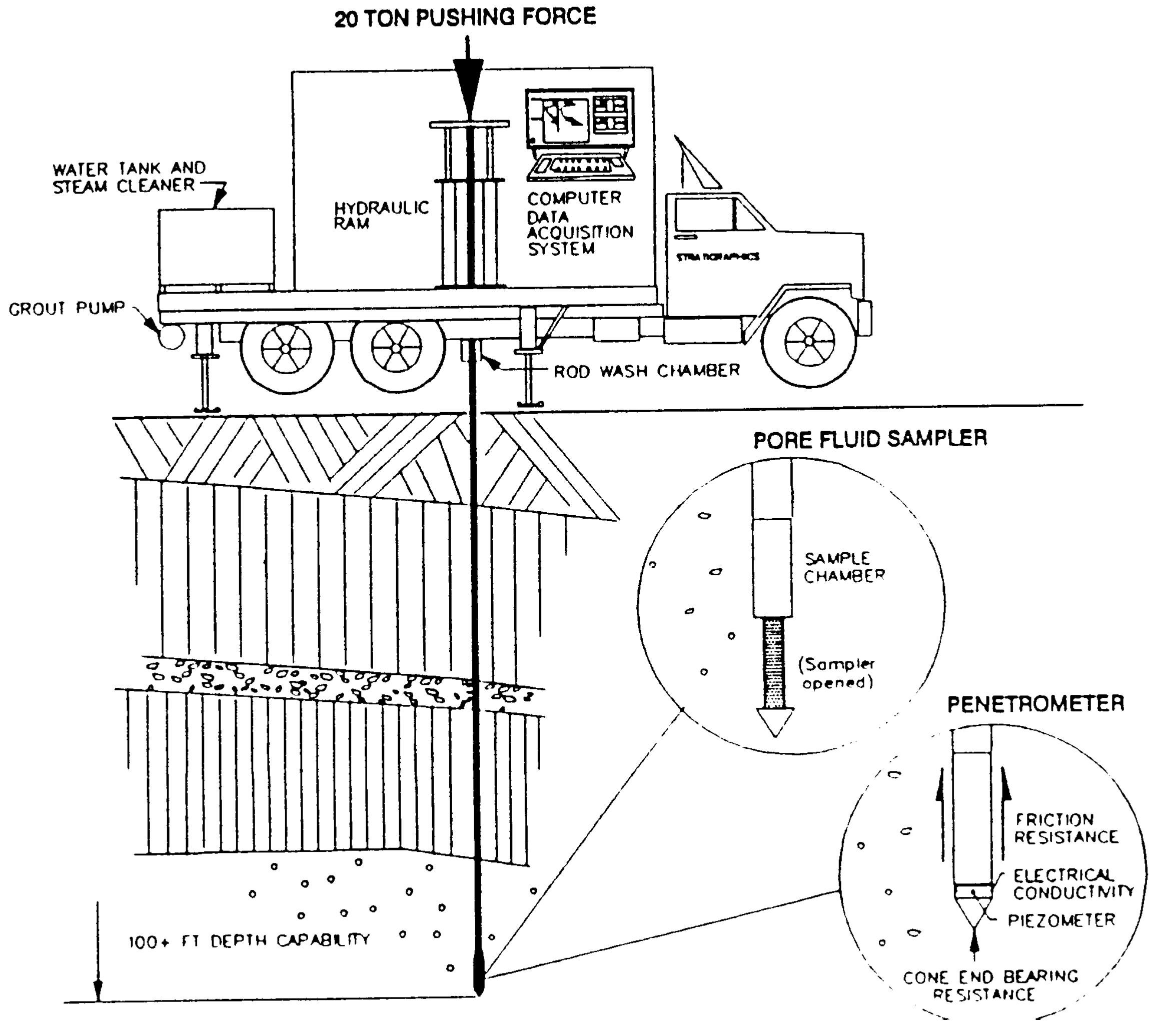
Cone penetrometers are best suited for sand, silt and clay deposits. Depths of 300+ feet (90+ meters) can be achieved in very soft unconsolidated materials; however, gravel, cobbles and dense or cemented layers reduce a cone penetrometer's effectiveness or may impede it altogether. Depending on the rig and site conditions, anywhere from 300 to 900 feet (90 to 275 meters) of geotechnical readings can be performed in a day. Site disturbance is minimal and there are no drill cuttings.

> **Important note:** All boreholes, including boreholes created by direct push methods, greater than 10 feet (3 meters) deep and all boreholes that intersect a water table must be abandoned in accordance with s. NR 141.25, Wis. Adm. Code. Specifically, the borehole should be grouted from the bottom to the top. With direct push methods, this may require changing the tool on the drive rod.

1.3.2 Discrete-depth Groundwater Sampling

Discrete-depth groundwater samplers are used during initial site investigations to provide preliminary information on the degree and extent of groundwater contamination. This information, along with subsurface stratigraphic data, can assist with determining the appropriate number, location and screening of permanent monitoring wells.

Discrete-depth groundwater samplers have been developed for use with conventional drill rigs (BAT Enviroprobe®, MK2 probe®, QED Hydropunch®, etc), cone penetrometer rigs, or with rigs designed to hydraulically hammer or vibrate the tools or probes to desired depths (Geoprobe®, Deidrich®, Stratiprobe®, etc.,). Some of these devices require that a groundwater sample be collected with a bailer or with a vacuum/suction pump. Other devices have a retrievable sampling chamber or vessel within the drill rod.


20 TON PUSHING FORCE
WATER TANK AND STEAM CLEANER
HYDRAULIC RAM
COMPUTER DATA ACQUISITION SYSTEM
GROUT PUMP
ROD WASH CHAMBER
PORE FLUID SAMPLER
SAMPLE CHAMBER
(Sampler opened)
PENETROMETER
FRICTION RESISTANCE
ELECTRICAL CONDUCTIVITY
PIEZOMETER
CONE END BEARING RESISTANCE
100+ FT DEPTH CAPABILITY

These devices are good preliminary screening tools and are very good at collecting discrete-depth groundwater data. They can accurately characterize variations in the distribution and concentration of contaminants that exist in discrete zones in groundwater. However, discrete-depth groundwater samplers cannot replace properly-constructed monitoring wells for collecting representative, high-quality groundwater samples.

Potential limitations of discrete-depth groundwater sampling devices include the following:

- Some designs are incapable of collecting groundwater samples at the water table surface.
- Some devices have excessively long collection times when obtaining groundwater samples from silt or clay formations.
- Most devices have relatively short screen lengths (<1 to 4 feet or 0.3 to 1.2 meters) that may miss contamination.
- Some devices have limited sample volume capabilities.
- The screens of these devices may allow appreciable quantities of fines to enter the sample chamber.
- It may be difficult, if not impossible, to properly develop the borehole to collect sediment-free samples or samples representative of the surrounding groundwater quality.
- These devices have soil type and depth limitations and are generally not capable of penetrating gravel, cobble, hard or cemented layers and certain sands.
- Boreholes created by these devices may be difficult to properly abandon in accordance with s. NR 141.25 Wis. Adm. Code.

Case studies

Clausen and Solomon (1994) used three different methods for defining the degree and extent of trichloroethene (TCE) and technetium (^{99}Tc), a man-made radionuclide, at a Department of Energy Facility located in western Kentucky. The authors used a van-mounted GeoProbe® which employs a hydraulic hammer to drive a 2.5 cm outer diameter (OD) rod, a Rhino® which employs an air operated hammer and vibrator to drive a 4.8 cm OD rod and a Mr. Missile® which employs a hydraulic hammer to drive a 4.8 cm OD rod. During groundwater sampling, a 1.3 cm OD polyethylene tube outfitted with a check valve at the bottom was inserted down the rod assembly of each tool. The top of the rod was capped and air pressure was applied to bring samples to the surface by air-displacement. A comparison of analytical results for TCE/^{99}Tc ratios for samples collected with the driven discrete-depth system and monitoring wells was comparable and yielded similar regression lines. The driven discrete-depth sample results strongly suggested a vertical distribution of residual dense nonaqueous phase liquid (DNAPL) in the groundwater and a DNAPL pool underlying the site. These were not previously detected by the permanent monitoring wells installed at the facility.

Strutynsky and Sainey (1992) used a cone penetrometer to determine a site's hydrostratigraphy in real-time and collected groundwater samples from a Hydropunch® to preliminarily define the degree and extent of a volatile organic compound (VOC) plume. The results were used to determine subsequent monitoring well locations. The Hydropunch® was successful in obtaining 22 groundwater samples out of 27 attempts. While the Hydropunch® worked well, there were some disadvantages: 1) It was not always clear if the well screen shield had opened; 2) minor seizing of the sampler parts occurred; and 3) there was slight bending of the sample barrel at forces > 10 tons. Use of the cone penetrometer, Hydropunch® and an on-site gas chromatograph allowed for minimal site disturbance and waste generation, the collection of high quality/high resolution hydrostratigraphic data, the optimal placement of monitoring wells, and meeting deadlines at a minimal cost.

Kaback et al., (1990) compared the ability of a Hydropunch® and four adjacent monitoring wells to collect similar groundwater sample data. Results for two of the wells showed excellent correlation with Hydropunch® analytical data. However, results for the other two wells showed variation. These other two wells were screened in the most concentrated part of the plume, which existed as a very thin lens close to the water table surface. However, the Hydropunch® design required that it be placed at least 5 feet (1.5 meters) below the water table to allow hydrostatic forces to fill it, and the Hydropunch® was unable to sample the plume near the water table surface. The study concluded that the Hydropunch® was an excellent screening tool for trace metals, pH and major cations and anions; however, contamination near the water table may be missed.

A similar study conducted by Bergen et al., (1990) looked at the Hydropunch®'s ability to reproduce VOC data collected from five adjacent monitoring wells. The study found that the analytical results for the Hydropunch® and well samples were statistically similar and that the Hydropunch® served as a good initial screening tool. Hydropunch® difficulties included: 1) Missing contaminants near the water table surface; 2) physical deformation of the sampler when hammered through well-sorted coarse sand layers; 3) sample collection times of up to two hours in silt and clay zones; and 4) the unit's filter mesh allowing significant intake of fines into the sample chamber.

2.0 SAMPLING PROCEDURES FOR MONITORING WELLS

2.1 OBJECTIVES, PLANS, PREPARATIONS AND DOCUMENTATION

Primary components of a successful groundwater monitoring and sampling program include: determining data objectives; developing and following an effective site-specific sampling plan; preparing carefully before sampling; and meticulously documenting each sampling event.

2.1.1 Data Objectives

Before monitoring, it is critical to identify and understand the purpose for monitoring and how the resultant data will be used. Groundwater quality data are collected to meet a variety of objectives, including, but not limited to, protection of public health and the environment, facility performance evaluations and assessment of groundwater contamination remediation efforts.

Establishing Data Quality Objectives

The data quality objective (DQO) process is a systematic planning process for determining the type, quantity, and quality of data and information necessary to make well-informed, valid and defensible decisions. DQOs clarify a project's goals and objectives. They explain what data and information will be used, and how and why it will be collected. DQOs also specify acceptable levels of uncertainty or errors in data, and the risks of making wrong decisions.

The following DQO process steps, presented in various USEPA guidance documents, describe project design optimization and can be used in varying degrees for large and small monitoring projects:

1) **State the Problem:** Concisely state the problem to be studied.
2) **Identify the Decision:** Identify what questions the study will attempt to answer and what actions may result.
3) **Identify Inputs to the Decision:** Identify the data and measurements necessary to resolve the decision. Consider any factors influencing the decision such as cost or public perception of risk.
4) **Define the Study Boundaries:** Specify the time periods and spatial area to which the decision will apply and when and where to collect data.
5) **Develop a Decision Rule:** Consider the parameters of interest, the action or cleanup levels and alternative actions. Choose among the alternative actions.
6) **Specify Limits on Decision Errors:** Determine tolerable limits on decision errors based on consideration of the consequences of making an incorrect decision.
7) **Optimize the Design:** Generate alternative data collection designs and choose the most resource-effective design that meets all DQOs.

For projects that collect groundwater data and measurements, or are responding to a groundwater quality standards exceedance, the following considerations should ensure that the data collected meets data quality objectives (DQOs):

- Regulatory objectives and requirements.
- Contaminant considerations.
- Sampling considerations.
- Data quality and quantity.
- Laboratory constraints: methods, limits of detection and analytical data quality.

Regulatory Objectives and Requirements

Chapter NR 140, Wis. Adm. Code, requires that all facilities, practices and activities that may affect groundwater quality and that are regulated by a state agency protect, monitor and remediate groundwater quality when necessary [see s. NR 140.03]. State agencies that regulate facilities, practices and activities include the Wisconsin Department of Natural Resources (WDNR), the Department of Agriculture, Trade and Consumer Protection (DATCP), the Department of Transportation (DOT), and the Department of Industry, Labor and Human Relations (DILHR). Each state agency that requires groundwater monitoring has specific statutes, administrative codes and guidance documents that describe their regulatory objectives and requirements.

Chapter NR 140 requires that groundwater samples must be collected using procedures specified by WDNR (i.e., this document and the accompanying *Field Manual*). Where no procedures are specified (e.g., procedures for collecting groundwater samples containing radioactive substances), other published sampling procedures may be used [see s. NR 140.16(1)]. Chapter NR 712.05 describes minimum qualifications for those people collecting environmental samples, including groundwater samples. Chapter NR 140 requires that groundwater quality samples be analyzed by a laboratory certified and registered under ch. NR 149. Chapter NR 149 establishes the minimum requirements for laboratories; however, if a project's objectives necessitate a higher level of quality, the laboratory may need to validate the analytical data to ensure it meets the project's DQOs.

Chapter NR 140 and the NR 700 series already include many of the important aspects of the DQO decision process. Chapter NR 140 specifies groundwater quality standards for substances detected in groundwater; these are action or cleanup levels. The NR 700 rule series includes the complete process that responsible parties must follow to report, investigate and clean up soil and groundwater contamination. This incorporates several aspects of the DQO process including identifying what data are needed, the study boundaries and investigation requirements, the response alternatives evaluation and decision process and action levels for soil. These aspects of the DQO process strongly encourage the most effective means to meet all project DQOs.

WDNR and other state agencies that monitor or require the monitoring of groundwater quality do so to meet one or more of the following regulatory objectives or requirements:

- Define the nature and extent of groundwater problems in Wisconsin.
- Reduce groundwater pollution and prevent contamination of groundwater.
- Provide a basis for facility or practice design, construction and operation.
- Evaluate a facility's or site's performance and environmental impacts.
- Comply with ch. NR 140, Wis. Adm. Code, groundwater quality standards.

- Protect public health, welfare and the environment.
- Define and sample potable wells at risk from groundwater contamination.
- Evaluate the need for a change or revision of a facility's or site's monitoring, design, construction, operation, waste treatment or disposal practices.
- Evaluate the need for prohibition or closure and abandonment of a facility or site.
- Meet Wisconsin Pollution Discharge Elimination System (WPDES) permits.
- Evaluate the degree, extent and environmental fate of groundwater contamination.
- Evaluate and verify the remediation of groundwater contamination.

Contaminant Considerations

Determining and evaluating the type, concentration and stability of contaminants and parameters collected or measured is important. The susceptibility of contaminants to extraneous contamination or loss during purging, sampling and handling will help define the rigor and stringency of chosen procedures and protocols.

During monitoring of contaminants that are unstable, subject to alteration during collection, or may be present at concentrations near the analytical detection limit, rigorous purging, sampling, handling and decontamination procedures are necessary. Sensitive substances such as volatile organic compounds (VOCs) and dissolved metals, usually analyzed and regulated at the micrograms per liter (µg/l) or parts per billion (ppb) levels, fall into this category. Strict and rigorous sampling procedures, QA/QC procedures and careful documentation of the sampling event are necessary.

On the other hand, routine compliance monitoring for major, stable ions (e.g., monitoring chloride ions at a wastewater spray irrigation site) that are not subject to alteration during sampling or handling can have less stringent and less rigorous sampling and handling procedures. QA/QC and documentation procedures used depend on project objectives.

Sampling Considerations

The larger and more complex a site's hydrogeology and contamination plume are, the more rigorous and detailed the sampling plan should be. The site's stratigraphy, hydrogeology and complexity in relation to the fate and transport of contaminants should be determined and evaluated. Any restraints or considerations these factors may place on establishing sampling procedures, QA/QC procedures and documentation procedures should be noted.

Timing and frequency of data collection are also important considerations. For example, pesticide concentrations in groundwater are most likely to be highest right after a recent rain and soon after application. Consequently, variations of pesticide concentrations in groundwater will likely be greatest in spring and summer. Another example is a site with residual petroleum contamination in soil directly above the water table. Concentrations of petroleum in groundwater may be highest soon after rains because water infiltrating through the soil will dissolve petroleum and, as the water table rises, residual petroleum in the soil will dissolve into the groundwater.

A common monitoring goal is to determine the actual concentrations of contaminants present in groundwater. Due to the nature of collecting groundwater samples, the true levels present in the groundwater may be underestimated. Ignoring analytical error and bias, how closely contaminant concentrations approach the actual concentrations present in the groundwater depends on how sampling and handling errors are controlled. Ultimately, sample integrity drives the quality of analytical results.

Overall Data Quality and Quantity Needs

The quality of a data set relates to the level of uncertainty or error inherent in a data set, usually expressed as the precision, accuracy, bias, representativeness, comparability and completeness of a data set. Unfortunately, determinations of data quality often focus solely on the laboratory component, overlooking or avoiding the significant contribution of sampling and handling.

Data quality for a specific project or site specifies the level of uncertainty that will be tolerated in a set of environmental data. The higher the data quality, the more confidence an individual will have in the accuracy and representativeness of a data set. The quality of a data set is expressed:

1) qualitatively as a specified set of procedures and protocols used for collecting the data (i.e., purging and sampling procedures) and

2) quantitatively as the amount of acceptable variation and error (precision, accuracy and bias) inherent in the data set attributable to sampling equipment, sampling procedures, analytical methods and the concentration of the contaminant in relationship to method detection limits.

Analytical laboratories are required to follow approved methods, specify quality control/quality assurance procedures, and keep detailed records. However, field sampling activities and procedures typically are not as defined or stringent as the analytical procedures. Because of this, the level of uncertainty inherent in a data set attributable to field sampling procedures and protocols is often difficult to quantify or is unknown. Therefore, identifying project data quality needs, creating and following a site-specific sampling and analysis plan and quality assurance/quality control plan and carefully documenting each sampling event will go a long way in controlling the uncertainty in the measurements and minimizing the risks to decision-making.

In addition to quality considerations, the quantity of data available is an important consideration, particularly during application of statistics to the data set. Data quantity is the number of samples needed to support the decision at the specified level of uncertainty. The question "How many data points do you need to make a decision?" is deceptively simple. Answering it may be considerably more difficult, particularly when you assess the risks of making the wrong decision. Anyone who has worked with a statistician to design a monitoring project realizes that it is frequently not practical or feasible to collect enough samples to achieve the desired level of certainty. The risks to decision-making must be weighed against physical, regulatory and fiscal constraints.

Quality assurance and quality control (QA/QC) requirements and procedures should match the level of data quality required and the DQOs derived for a site or project. Refer to Section 2.10.1

for further discussion of QA/QC requirements, procedures and development of a QA/QC plan. Brynes (1994) and EPA (1995 and QA/G-4 Interim final) provide detailed discussion of the overall data quality objectives process.

Laboratory Constraints: Methods, Limits of Detection and Analytical Data Quality

How close the laboratory's limit of detection for a contaminant is to the suspected concentration and regulatory limit (e.g., ES or PAL) for the project should indicate the level of care needed in sampling for a given contaminant or parameter. For example, if contaminants may be present near the analytical limit of detection, then particular attention should be paid to sampling procedures to avoid contaminating the sample or losing the contaminant.

The U.S. Environmental Protection Agency (EPA) has identified five separate analytical quality levels (EPA 1987) that may be appropriate for a site or project. **Table 1** summarizes the levels and their appropriateness in relation to data uses, type of analysis, limitations, and the data quality for which each level should provide. For most groundwater monitoring and contamination investigation/remediation projects regulated under s. 144.76 or 144.442, Wis. Stats., and not subject to CERCLA or RCRA requirements, the I, II and III analytical levels will meet data quality needs. Levels IV and V may be appropriate for special needs such as Superfund sites and obtaining strong, legally defensible results.

- Level I data are collected with portable field screening instruments such as an organic vapor instrument (e.g., PID, FID). Results are not compound specific, detection limits are high (e.g., ±mg/L) and results are in real time (i.e., seconds to minutes).

- Level II data are collected with more sophisticated portable analytical instruments (e.g., mobile laboratory equipped with a gas chromatograph). Level II data quality depends on the calibration standards used, reference materials, sample preparation equipment and training and skill of the instrument's operator. Results are available within minutes or several hours. Level I and II data are used in site characterization and defining the degree and extent of contamination.

- Level III data are analyzed at a non-portable laboratory and are commonly analyzed using SW-846. In Wisconsin, this data must be analyzed by a laboratory certified under ch. NR 149, Wis. Adm. Code. The laboratory does not have to be CLP-certified and the data is not subject to special validation and documentation procedures.

- Level IV data are analyzed by a Contract Lab Program (CLP) analytical laboratory following CLP procedures. Level IV data analysis is characterized by rigorous QA/QC protocols and documentation. In Wisconsin, certain projects may require CLP protocols and data packages but allow a non-CLP laboratory to perform the analysis. In such cases, ch. NR 149 requirements are no longer applicable. However, analyses not subject to CLP protocols must follow Ch. NR 149 requirements and any additional QA/QC and reporting specified in the project plan and data validation.

- Level V data are analyzed by non-standard analytical methods. Analysis may or may not be performed by a CLP laboratory (CLP special analytical services are level V). Analytical method development or modification of an existing method may be required for a specific constituent or to meet required detection limits.

(Page left blank)

TABLE 1: SUMMARY OF ANALYTICAL LEVELS APPROPRIATE TO DATA U

ANALYTICAL LEVEL	DATA USES	TYPE OF ANALYSIS	LIMITATIONS
LEVEL I	• Site characterization • Monitoring	• Total organic/inorganic field instruments • Field test kits	• Results are not compound specific • High detection limits • Naturally-occurring interferences
LEVEL II	• Site characterization • Remedial alternatives evaluation • Engineering design • Monitoring	• Variety of organics by GC; inorganics by AA • Tentative identification; analyte specific • Detection limits vary from low ppm to low ppb	• Tentative identification • Techniques and instruments limited mostly to volatiles and metals
LEVEL III	• Site characterization • Remedial alternatives evaluation • Engineering design • Monitoring • PRP determination • Risk evaluation	• Organics/inorganics using SW-846 • In WI, laboratory must be ch. NR 149 certified • RCRA characteristics tests	• Tentative identification in some cases • Data is not subject to validation and documentation as CLP
LEVEL IV	• Remedial alternatives evaluation • Engineering design • PRP determination • Risk evaluation	• CLP laboratory following CLP procedures • Organics/inorganics by GC/MS; AA; ICP • Low ppb detection limits	• Rigorous QA/QC procedures may cause long turn-around time for results
LEVEL V	• PRP determination • Risk evaluation	• Non-conventional parameters/methods • Method-specific detection limits • Modification of existing method	• May require method development/modification • Mechanism to obtain services requires special lead time • May or may not be a CLP laboratory

Maintaining Data Quality Objectives

Meeting and maintaining an established level of data quality can be accomplished by:

1. Following a sampling and analysis plan (SAP) and quality assurance/quality control (QA/QC) plan specifically tailored to a site or project.

2. Documenting the samples collected, measurements taken and procedures followed during each sampling and monitoring event. The SAP and QA/QC procedures can serve as documentation of equipment and procedures used; however, any deviations from the established procedures and protocols must be documented.

3. Strictly adhering to the DQOs and quality assurance/quality cotrol (QA/QC) procedures established for the project.

2.1.2 Developing Site-specific Plans

Sampling and Analysis Plan (SAP)

A sampling and analysis plan (SAP) should be site-specific and should bring the sampling and monitoring procedures and protocols, data quality objectives (DQOs) and other project requirements into one clear plan. The sampling plan should document the equipment and procedures used during a sampling event. The procedures and protocols specified in the SAP should be consistently followed <u>throughout the life of a project</u>. Any deviations, including reasons for the deviations, should <u>always</u> be clearly documented.

Depending on a project's complexity and any regulatory requirements, a SAP may be fairly short and simple (e.g., small seepage lagoon, 3 monitoring wells, sampled quarterly for indicator parameters), to long and complex (e.g., CERCLA, RCRA, or Superfund sites). Chapter NR 716 specifies site investigation work plans, field investigations and sampling and analysis requirements for responsible parties investigating a hazardous substance discharge (e.g., underground storage tank discharge) subject to regulation under s. 144.76 or 144.442, Wis. Stats.

If a SAP is modified during the life of a project, the modifications must be considered when evaluating the data generated from the project. Refer to Section 2.5, "important note," related to the validity, representativeness and comparability of a project's groundwater data.

All the following items may not be necessary for a project's SAP. Include those items applicable to the specific project, established data quality objectives and as required by applicable state and federal rules and regulations:

1. The project or site name and location (include maps).
2. A brief history of the site including chemical use inventory/history, land use, known and suspected spills, environmental media affected, etc,.
3. Regulatory objectives and data quality objectives (DQOs).
4. Type, concentration and form (e.g., free product, dissolved) of contaminants and parameters to be measured and sampled.

5. Transportation to the site and site access arrangements (e.g., meeting times, keys, permission).
6. Sampling team personnel and their duties.
7. The location of all wells (include map), well names or numbers (e.g., Wisconsin Unique Well Numbers), well diameters, screen lengths and well depths.
8. Order in which wells are sampled, prior site sampling history and problems/constraints.
9. Which documentation sheets and forms (e.g., well specific field sheet, chain of custody form, etc.,) should be completed for each sampling/monitoring event.
10. Equipment, procedures and protocols for:
    a. measuring static water level,
    b. measuring and sampling immiscible layers,
    c. purging and sampling wells,
    d. filling sample containers and preserving samples,
    e. taking water quality measurements and
    f. filtering samples.
11. Laboratory analytical methods and limits of detection for each contaminant being sampled.
12. Laboratory analytical data submittal form (e.g., electronic, tables, forms) and regulatory data submittal deadlines (e.g., 10 days).
13. The QA/QC plan and procedures including the handling, storing, transporting and shipping samples and the collection of quality assurance samples. The QA/QC plan and procedures should be incorporated into the SAP, or less preferably, can be created as its own separate plan (see Section 2.10.1).

Health and Safety Plan (HSP)

The Code of Federal Register 29 CFR Section 1910.120 and Occupational Safety and Health Association (OSHA) includes many of the requirements for individuals performing hazardous waste operations and emergency response and should be referenced. While specific health and safety concerns and regulatory requirements are beyond this document's scope, some health and safety considerations common to groundwater contamination and monitoring activities include:

1. A hazard analysis for each site task (including a list of contaminants, concentrations and associated health hazards).
2. List of sampling personnel, site safety and health supervisor, hazardous waste training, and personnel medical monitoring received.
3. Level and type of personal protective equipment required (e.g., level A, B, C, or D). Check the compatibility of the personal protective equipment with the types and concentrations of known or suspected contaminants at the site. Manufacturers of personal protective equipment often have charts and tables for choosing appropriate types and materials of protective wear applicable to a variety of contaminants.
4. Frequency and type of air monitoring, personnel monitoring, environmental sampling and instrumentation to be used.
5. Site control (access) measures.
6. Personal hygiene and decontamination procedures.
7. An emergency response and contingency plan (including emergency phone numbers and map to nearest medical facility).
8. Work limits for inclement weather, confined space entry, etc.
9. A spill containment plan.

Another potentially useful resource related to health and safety includes the NIOSH *Pocket Guide to Chemical Hazards*, DHHS (NIOSH) Publication No. 90-117. Copies of this and other NIOSH documents are available by calling (513) 533-8287.

2.1.3 Other Preparations

Careful planning, and advanced checking and preparing of equipment before heading into the field will save time, money and problems.

Pre-field Work Procedures Checklist - Monitoring Wells

The following checklist should help you conduct a smooth, effectively-prepared groundwater sampling program for your project. This checklist, in abbreviated form, is also included in Appendix A of the *Groundwater Sampling Field Manual, PUBL-DG-038 96*

All the following procedures may not be necessary for each sampling event. Use those procedures applicable to your sampling plan or customize this list as appropriate.

<u>Logistics</u>

1. Arrange for site access with the land/home/facility owner and tenants. Besides avoiding site access delays, pre-arranging site access will help maintain good relations with the site's owner. This will also provide a good opportunity to update the owner on progress at his/her site and answer any questions he/she may have.

2. Locate the nearest post office, UPS office, or Fedex drop off spot if you will be mailing the samples from the field. (UPS has a 70 pound weight restriction per container.) Make sure you have the proper materials for shipping samples (e.g., sufficient coolers and ice).

3. Determine how the purge water and wastewater will be stored and discarded. If the purge water and wastewater will be disposed of into a sanitary sewer, contact the water utility department and receiving wastewater treatment facility to obtain permission and establish where, when and how much wastewater will be disposed of into the sanitary sewer system.

<u>Laboratory Arrangements</u>

1. Select a laboratory to perform the sample analysis. Pay careful attention to the laboratory selection process. Selection based on price and turn-around alone may doom the project. Evaluate quality objectives for the project and laboratory analyses. Evaluate reporting requirements and other considerations specific to the project. Check that the laboratory (and subcontracted laboratory) is certified or registered under ch. NR 149 to perform the required sample analysis. Check that the laboratory will follow the proper analytical methods and can meet required limits of detection.

2. Discuss with the laboratory who will supply what sample containers. If the laboratory will supply some or all of the containers, make arrangements for delivery of the number and type needed **- get extras!** Don't forget QA/QC sample containers and trip blanks if VOC samples will be collected. Appendix C of the *Groundwater Sampling Field Manual,* specifies container types and provides recommendations on the minimum sample volumes for a variety of analytical parameters.

3. Discuss sample preservation, holding time and shipping requirements with the laboratory. Some laboratories provide preservative already in sample containers, or in other containers (e.g., ampules) that you can later dispense into the sample containers. Discuss QA/QC expectations and the type of information that should accompany analytical results (e.g., LOD and LOQ data).

4. Inform the laboratory of when and how many samples will be sent. This will help the laboratory prepare for analyzing your samples and meet sample holding times.

5. Familiarize yourself with chain of custody and other sample tracking procedures.

6. Discuss any other procedures required by the laboratory (e.g., noting gross sample contamination, field turbidity readings if metal samples are to be analyzed). Some laboratories request previous analytical results for each well to help determine appropriate sample dilutions up front.

7. Include in the contract quality objectives (QA/QC, MDLs, etc), project-specific requirements (e.g. providing raw package with the report) and any special agreements made with the laboratory. This helps avoid misunderstandings about expectations and may provide additional tools to deal with data that falls far short of quality objectives.

Site History

1. Review the sampling and analysis plan (SAP) and past water quality and sampling data.

Equipment and Field Preparation

1. Review the SAP and QA/QC plan or equivalent. Refer to Section 2.1.2 for developing a SAP and Section 2.10 for developing a QA/QC plan.

2. Organize groundwater monitoring and sampling equipment. Do this at least one day ahead of the scheduled sampling day. Refer to Appendix A of the *Groundwater Sampling Field Manual* and use the "Equipment Checklist - Monitoring Well Sampling" or customize your own equipment checklist.

3. Check that sampling equipment is in good working condition:

   - ✓ Test and recharge/replace batteries as necessary.
   - ✓ Test the equipment with tap water or calibration standards when possible.
   - ✓ Inspect the equipment for defects, loose bolts, frayed wiring, etc.

- ✓ Check the instruments' ability to calibrate and function properly. Check its ability to operate in very cold, hot or wet weather.

4. Check that all the equipment is properly decontaminated and stored for transport.

5. Complete the well-specific field sheet (WSFS), data logs or other field data sheets as much as possible before going to the field.

<u>Health and Safety Equipment and Preparation</u>

1. If applicable, review the health and safety plan (HSP). Refer to Section 2.1.2 and applicable federal, state and local laws, codes and requirements related to health and safety requirements.

Equipment Checklist - Monitoring Well Sampling

A complete monitoring well sampling equipment checklist is included in Appendix A of the *Groundwater Sampling Field Manual, PUBL-DG-038 96* All of the items included in the checklist may not be necessary for each sampling event. Modify and customize this list as necessary and appropriate.

2.1.4 Documentation

Meticulous documentation of monitoring and sampling data and collection/measurement procedures is essential. Documentation provides a permanent record of data collected, equipment and procedures used, sampling personnel, and problems that occur at a site. This information will help ensure that data are collected consistently and that deviations in protocols are noted for later evaluation. Careful documentation also helps prepare a project's data for legal scrutiny.

Clearly document the methods, procedures and equipment you use to collect groundwater data in the data reports you generate for a site or project. Also, clearly document any deviations from the standard sampling and monitoring protocol, along with a discussion of potential effects on the data.

Documentation of the Sampling Event

1. **Site-specific Sampling and Analysis Plan (SAP) or Equivalent.** A SAP or other sampling plan should act as documentation of the sampling event. All sampling personnel should read it before heading out to the field and should bring it to each sampling event. Document any <u>deviations</u> from the sampling plan; you can use the "Field Procedures Documentation" sheet included in Appendix A of the *Groundwater Sampling Field Manual* to document any deviations.

2. **Well Specific Field Sheet - Monitoring Wells** Document well-specific purging, sampling and field water quality measurement data on this sheet (included in Appendix A of the *Groundwater Sampling Field Manual*). Or, customize your own data sheet. Hand-held data loggers are becoming popular because they provide a permanent record of well data that can be easily down-

loaded to a computer.

3. **Field Procedures Documentation.** A SAP or other sampling plan should act as documentation of sampling procedures; however, if a sampling plan is not available, use the "Field Procedures Documentation" sheet included in Appendix A of the *Groundwater Sampling Field Manual*. You can customize this sheet to meet specific needs.

4. **Chain of Custody Form (Appendix A).** Document the possession of groundwater samples by filling out chain of custody or other sample tracking forms. Complete this form for every sampling event no matter the size of the sample set. If a project is later subjected to legal action, chain of custody procedures and whether they were followed will likely be an important part of the case.

2.2 MEASURING STATIC WATER LEVEL

The measurement and interpretation of hydraulic head data are important components of any groundwater monitoring project. A basic understanding of hydraulic head is necessary before interpreting such data. A water level measurement collected from a well represents hydraulic head. Hydraulic head is the sum of the fluid velocity, elevation head and pressure head in a well. Groundwater flow velocities in porous media are extremely low and therefore, groundwater flow velocities are commonly ignored when calculating hydraulic head. Therefore, hydraulic head is the sum of the elevation head (feet or meters) and pressure head (fluid pressure divided by fluid density times acceleration of gravity) as expressed by:

$$h = z + h_p$$

h = hydraulic head
z = elevation head
h_p = pressure head

Technical note: Technically, all hydraulic head measurements are obtained using piezometers. Classically, a piezometer is defined as a pipe open at the top and bottom that measures hydraulic head at a discrete point (i.e., the bottom open portion of the pipe) in groundwater. However, groundwater professionals in Wisconsin today typically refer to piezometers as only those wells that are sealed below the water table. This is technically incorrect as water table wells (i.e., monitoring wells screened to intercept the water table) are piezometers where the pressure head equals zero (atmospheric pressure). To avoid confusion, this document refers to piezometers as those wells sealed below the water table.

As long as the water table surface intersects a well's screen, water level measurements collected from such a well represent the water table surface elevation (i.e., elevation head only: pressure head = 0 and is therefore ignored). This type of well is referred to as a "water table well." If a well is sealed below the water table surface, water level measurements collected from such a well represent the potentiometric surface (i.e., elevation head + pressure head) as measured in the well (i.e., the center or average of the well screen and filter pack area). This type of well is referred to as a "piezometer." A piezometer must be sealed below the water table (i.e., the well screen, filter pack and fine sand sealed below the water table) if it is to measure both the elevation head and pressure head in the groundwater system. The term "monitoring well" is used to refer to both water table wells and piezometers.

Figure 2 illustrates the concepts of the water table surface and respective water table well, potentiometric surface and respective piezometer, unconfined and confined aquifers, a perched water table and springs.

Dalton et al., (1991) provide a good discussion on collecting and interpreting hydraulic head data. Fetter (1988) and Freeze and Cherry (1979) provide detailed information regarding hydraulic head data and their relation to the aquifer system.

2.2.1 Technical Considerations

Important technical considerations for collecting accurate water level measurements include:

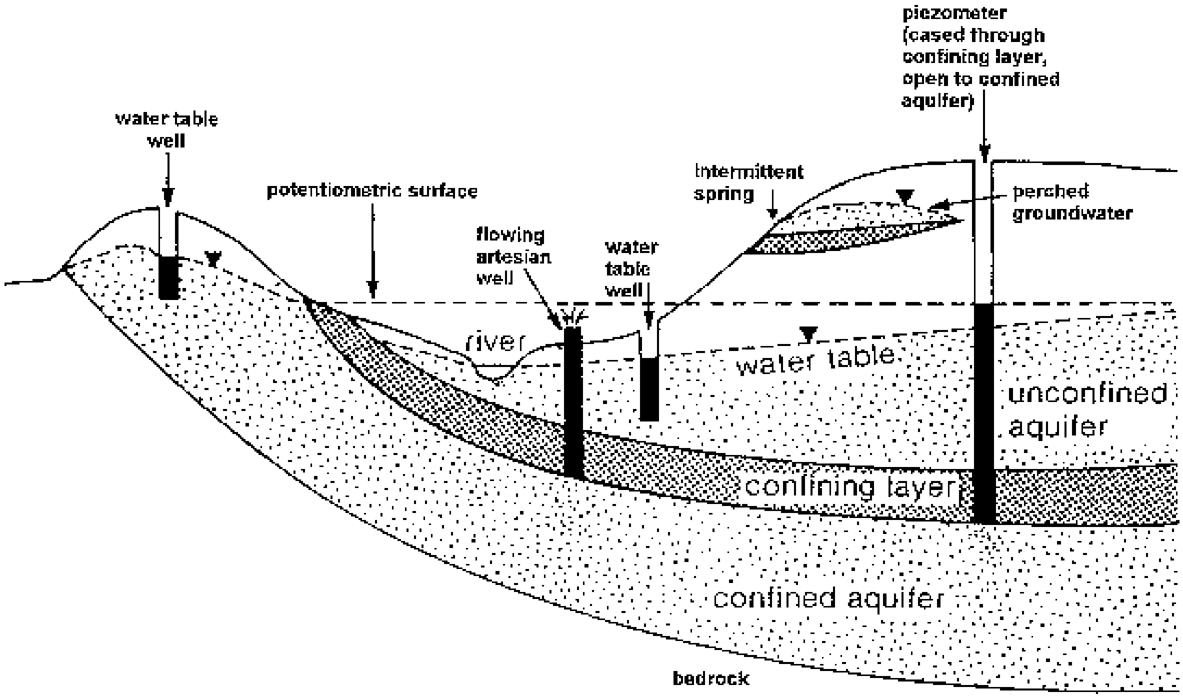
1. **Measure the static water level for a well before purging, sampling or inserting any instrument or device into a well**. If a well is purged, sampled, or a device is inserted into a well before measuring the static water level in the well, the measurement will not represent the static "undisturbed" water level or hydraulic head existing in the well.

2. **Collect measurements from all wells on the site as quickly as possible.** The best method is to collect measurements from all of the site's wells before doing any other tasks on the wells. This may be impractical and too time consuming for some sites. Typically, you take a water level measurement, sample the well, measure the next well's water level, sample that well, and so on. This method is acceptable if you collect all water level measurements at a site on the same day and the barometric pressure for that day does not change significantly (e.g., changing high or low pressure, advancing storm, etc.,). If the barometric pressure does change significantly during collection, a second round of measurements may be appropriate.

3. **Collect measurements in the order of least-to-most contaminated wells.** Furthermore, decontaminate the measuring device between each well to prevent cross-contamination. Do not let any parts of the instrument or tape touch the ground or any contaminated surface.

4. **Read measurements from the top of the casing or a reference elevation on the well.** This is usually a permanently and clearly-marked or notched spot located at the highest point on the top of the well casing. All top-of-casing or reference elevations must be surveyed to a common point of known elevation so that the water level measurements can be converted to groundwater level elevations, usually expressed as feet above mean sea level (MSL) or as USGS datum. Water level measurements must be accurate and precise to ±0.01 foot (± 0.25 cm.).

5. **Whenever possible, use one measuring device and one person operating it for all wells at a site during each sampling event.** Better yet, use the same measuring device and same person for all wells at a site over the life of a project. This will help ensure that water level data are accurate and comparable. If more than one measuring device is used, check both instruments against a calibrated standard, the same well, and against each other to ensure that they provide the same water level measurements. If necessary, use a correction factor to equalize the readings. Do this after checking each device to determine which tape length is correct.



Modified from Brassington, 1990

6. **After removing a water/air-tight well cap (e.g., flush mount piezometer), allow the pressure within the well to stabilize.** This is necessary because water/air-tight well caps do not allow the water level in the well to equalize with the ground surface atmospheric pressure as long as the well cap is in place. This is especially important for wells screened in silt and clay (low permeability) formations. Take several measurements spaced several minutes apart to confirm that the water level in the well has stabilized.

2.2.2 Equipment and Procedures

Equipment and procedures used for taking water level measurements vary substantially. Choose water level measuring devices based on their accuracy, precision, ease of use, reliability, durability, ease of decontamination and cost. Under most circumstances, WDNR requires that water level measurements be read to the nearest 0.01 foot (0.25 cm).

Water level measuring devices typically are either manual, non-recording devices or continuous measuring devices that provide a paper or electronic record of changing water levels over time. Although not exhaustive, the following discussion describes equipment and methods most frequently used by groundwater professionals. You can find specific procedures for collecting water level measurements with the first three devices in the *Groundwater Sampling Field Manual*, Section 2.2.

Table 2: Manual methods of water level measurements in groundwater monitoring wells (modified from Dalton et al., 1991).

Method	Accuracy (Feet)	Major Interference or Disadvantages
Electronic	0.01 to 0.1	Cable wear or kinks; hydrocarbons on water surface.
Popper	0.01 to 0.1	Well depth; well and ambient noise; operator skill; well pipes and pumps; tape clinging to well casing.
Indicator substance	0.01	Casing condensation; depth to water unknown; **indicator substance may affect the chemical characteristics of groundwater samples**.
Transducers	0.01 to 0.1	Temperature changes; electronic drift; blocked capillary.
Air-lines	≥0.25	Air line or fitting leaks; gauge inaccuracies; operator error **(not acceptable for monitoring well water level measurements)**.
Floats	0.02 to 0.5	Float or cable drag and stretch; float size and lag.
Ultrasonics	0.02 to 0.1	Well's temperature gradient; well pipes and pumps; well depth; casing joints.

2.2.3 Electronic Methods

These devices commonly operate by completing a circuit between two electrodes housed in a probe. When the electric probe contacts a water surface, a light, amperage gauge, or buzzer signals the operator that the probe has intersected a water surface. Most of these devices are manually-operated, non-recording devices. The operation of other electrical methods relies on such physical characteristics as resistance, capacitance or self-potential to produce a signal (Dalton et al., 1991).

Probably the most commonly-used electrical method is the electronic water level indicator. **Figure 3** illustrates the use of an electronic water level indicator. This device may be subject to measurement errors due to the probe contacting condensation on the inside wall of a well's casing or electrical problems with the device. Other potential sources of measurement errors include kinks in the cable, inaccurate gradation, or the banded measuring marks on the cable becoming loose and sliding. Check the measuring cable for proper length and gradation at least quarterly against a steel tape or some other accurate means of length calibration. Also, regularly check batteries and electrical connections. You may want to bring along another device (e.g., popper) as backup in case the electric method malfunctions.

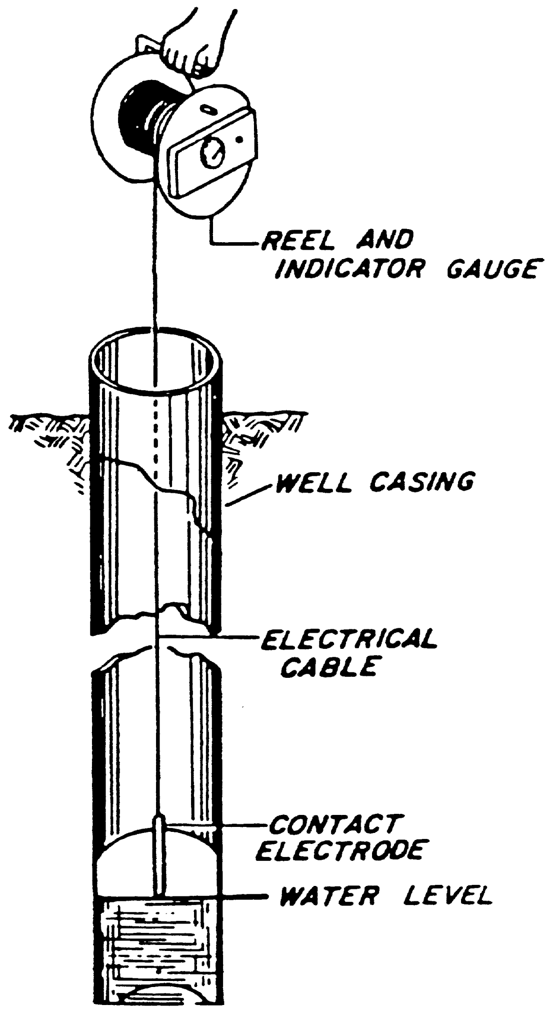
If there is a substantial layer of floating hydrocarbons (i.e., immiscible layer) in a well, you cannot reliably make a water level measurement. Refer to Section 2.3 for precautions related to the effect an immiscible layer may have on water table elevation measurements.

Electronic water level indicators can provide fast and accurate water level measurements during baildown tests, slug tests and aquifer pumping tests. These devices are best suited for piezometers during these tests; cascading of water in a water table well's screen may provide false water level readings. When conducting baildown, slug or aquifer pumping tests on monitoring wells, transducers provide the simplest and most accurate water level measurements.

2.2.4 Poppers

A simple device known as a "popper" is a quick, inexpensive and commonly-used method for measuring the water level in a well. This device is also a manually-operated, non-recording method. **Figure 4** illustrates a common design for the popping device consisting of a metal cylinder 1 to 1.5 inches in diameter, 2 to 3 inches long and including a hollow bottom. The metal cylinder (i.e., popper) is attached to a non-stretching flexible tape or steel measuring tape.

To take water level measurements with this device, you lower the popper into the well until you hear a "pop" sound. This indicates that you've reached the water surface. By repeatedly raising and lowering the popper onto the water surface and listening for the "pop" sound, you determine the depth to water. Some practice is required to determine at what point the popper contacts the water surface. The precision and accuracy of this technique highly depend on the user's skill and the well's depth (more accurate for shallow wells). You may also use the popper for measuring well depth by lowering it through the water column until the tape slackens. Slowly pull the tape up until it just becomes taut again; this is the well depth.


REEL AND
INDICATOR GAUGE
WELL CASING
ELECTRICAL
CABLE
CONTACT
ELECTRODE
WATER LEVEL

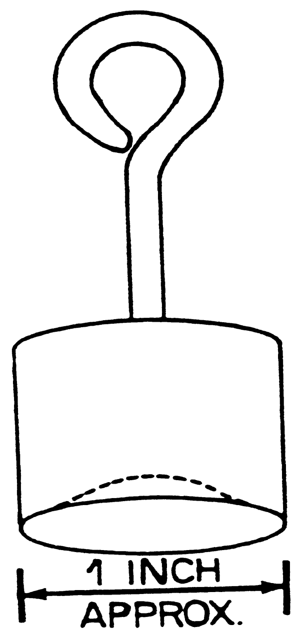

1 INCH
APPROX.

Figure 3: Electronic water level indicator

Figure 4: Common “popper” design

When a popper is connected to a tape, no length corrections should be necessary (i.e., depth to water measurements can be measured directly without adding or subtracting the length of the popper). Steel tape is recommended over flexible tape. Flexible tape can stretch and therefore should be calibrated quarterly against a known length standard. A high-quality steel tape or metallic monuments anchored in concrete are acceptable calibration methods.

Although simple and inexpensive, the popper method is prone to errors and measurement difficulties. If the water table intersects the well screen, if the well has a high gas content, or if the well is near a noisy area, the "pop" may be difficult to hear. Wet tape, especially wet flexible (non-steel) tape, may stick to the well casing making it difficult, if not impossible, to collect accurate measurements. Floating hydrocarbons in a well may also interfere with collecting accurate measurements. Be prepared with an alternate method for measuring water level when leaving for the field.

2.2.5 Indicator Substance

> **Important Note:** The indicator substance used to coat a measuring tape may contaminate the groundwater in a well and subsequent samples collected from that well. If an indicator substance is used, the user **must ensure** that the indicator substance will not contaminate the well or subsequent samples. If there is any doubt, choose another water level measurement method.

According to Dalton et al., (1991), and others, the coated tape (wetted tape) is one of the most accurate techniques for measuring water level. Equipment used for this technique commonly includes flexible or steel tape (recommended), carpenter's chalk or another indicator substance, and a slender metallic weight, typically a lead weight. Substances that change appearance are recommended over substances that wash away into the well. Steel tapes and hand reels are commercially available for lengths up to 1,000 feet (305 meters); however, shorter lengths are recommended due to their lighter weight and lower cost (Dalton et al., 1991). Check the length of the measuring tape, especially flexible tape, quarterly against an acceptable standard.

To collect a water level measurement using this method, coat the bottom 3 feet (1 meter) or so of the tape with the indicator substance and lower the tape slowly 1 or 2 feet (< 1 meter) into the water column. When the coated portion of the tape is lowered, the water either changes the appearance of the indicator substance or washes it away. The depth to water equals the tape reading at the top of the casing or reference elevation minus the wetted length of the tape. With a steel tape and sufficient operator skill, the precision and accuracy of this method is ±0.01 foot (± 0.25 cm).

Condensation on the well's casing wall may wet the tape as it is lowered, thus causing measurement errors. In addition, if the approximate depth to water is unknown, too little or too much of the tape may be lowered, thereby requiring a number of attempts.

2.2.6 Transducers

A transducer can act as a discrete or continuous measuring device. These devices lend themselves well to recording time vs. drawdown/recovery data typical of bail down, slug and aquifer pumping tests. They are also useful for determining long-term changes in water elevations when evaluating changing groundwater flow directions and fluctuating groundwater elevations.

Pressure transducers commonly consist of a silicon-based strain gauge pressure sensor with a 4-20 milliampere (mA) current transmitter. Other transducers on the market include the vibrating wire pluck (VWP) pressure transducer and the vibrating strip pluck (VSP) force transducer coupled with buoyancy cylinders (**Figure 5** - Dalton). The VSP force transducer is recommended over the VWP pressure transducer for obtaining precise measurements of water level changes.

Pressure transducers are available for pressures ranging from 5 to 500 pounds per square inch (psi), but typically transducers of 5 to 25 psi are used for monitoring groundwater levels. Transducers are rated in terms of their precision over their full psi range. A 0-5 psi transducer will provide measurements that are twice as precise as a 0-10 psi transducer of equal precision (Durham and Bumala, 1992). For example, a 0-5 psi transducer rated at 0.01 percent will provide measurements accurate to the nearest 0.01 foot while a 0-25 psi transducer rated at 0.01 percent will provide measurements to the nearest 0.05 foot (Dalton et al., 1991).

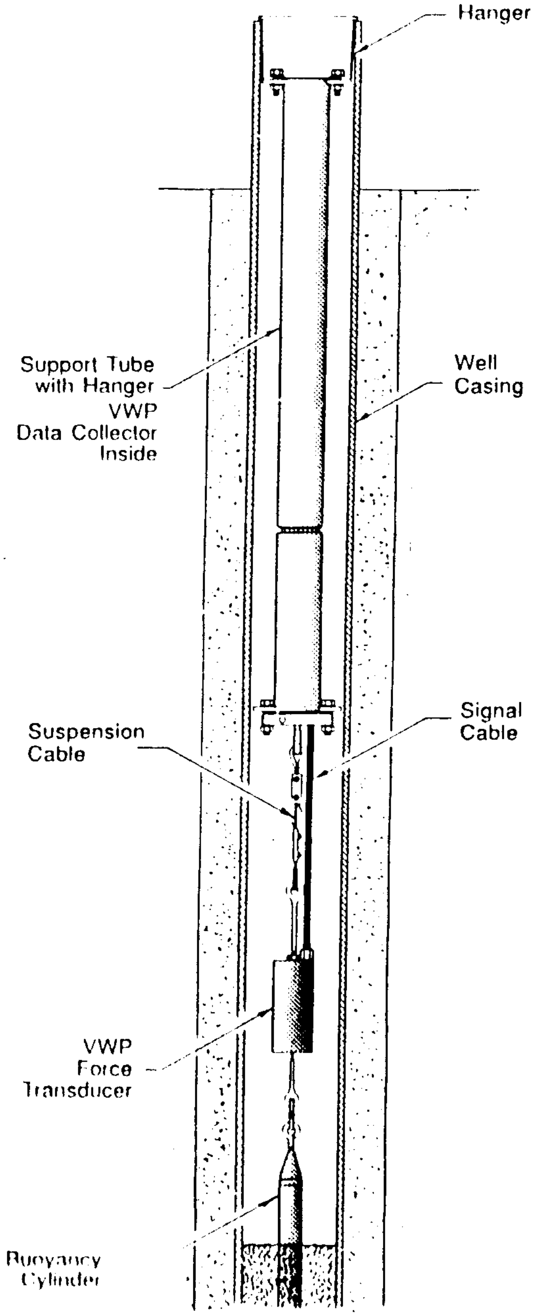
Pressure transducers commonly have a small capillary tube vented to the atmosphere that allows the transducer to automatically compensate for barometric (atmospheric) pressure. Pressure transducers measure the pressure head (water column) above the transducer. Pressure transducers are usually connected to a data logger that contains microprocessors to convert pressure information to feet or meters of water column above the transducer or depth to water from the top of the well casing. The data can easily be downloaded to a computer and subsequently used to calculate an aquifer's hydrogeologic properties.

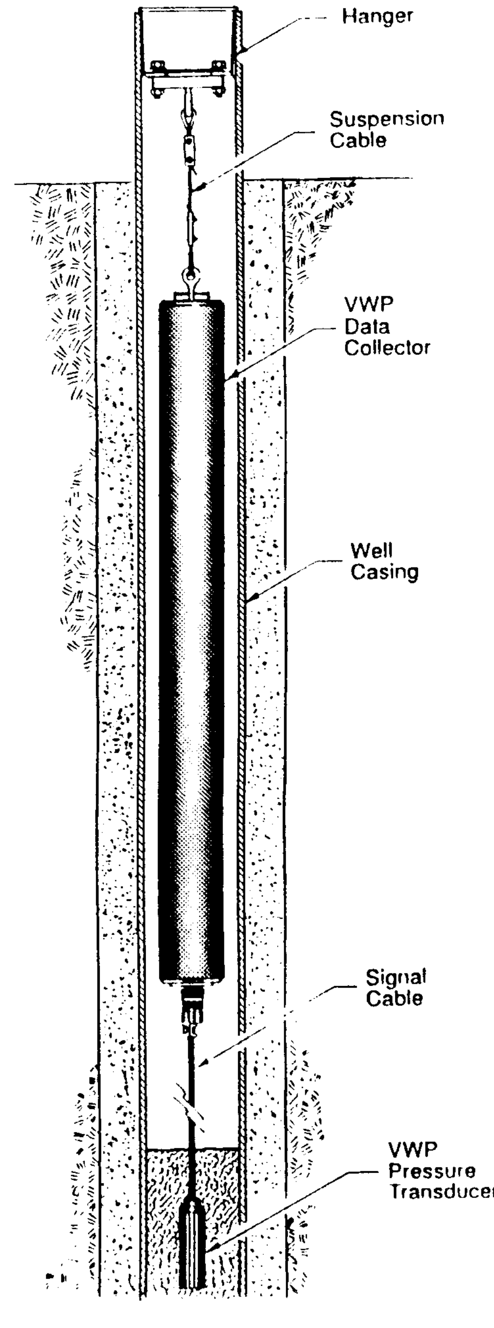
The precision, accuracy, calibration, reliability and operating procedures for pressure transducers and their accompanying data controller units vary throughout the industry. Various transducer systems offered on the market should be carefully researched to ensure that the chosen system meets the data collection needs and required accuracy for a particular project.

2.2.7 Air-line or Bubble Tubes

Air-line and bubble tubes are commonly used on water supply wells where the well's static and pumping water levels must be frequently observed and recorded. While air-line and bubble tube measurements may provide acceptable water-level data for water supply wells, they do <u>not</u> provide water level data accurate enough for monitoring wells.

To collect water level measurements, you install a small-diameter (typ. <0.4 inches) hollow rigid tube of known length into the well. The tube may be made of copper, plastic or steel and must not have any bends or kinks. The air-line and fittings must be air tight and the tube end submerged several feet below the lowest expected water level. The pressure gauge and air or





other gas source is attached to the air-line. Measurements taken on deep wells usually employ a small air compressor while measurements on shallow wells may use a hand pump.

After the tube is completely filled with air (when the air pressure measured by the gauge stops rising and stabilizes), it is ready to collect water level measurements. Air pressure changes measured by the gauge are used to calculate water level changes in the well. A pressure gauge calibrated in feet of water is preferred to gauges calibrated in psi. For gauges calibrated in psi, convert these measurements to feet by multiplying psi by 2.31.

2.2.8 Float Method

For this method, you attach a float or buoyant cylinder to a length of steel tape or wire and suspend it via a pulley assembly into the water column. You attach a counter weight to the steel tape or wire opposite the float. Simple devices of this type employ a chart recorder, typically a marking pen and graph, which records water level changes for many months, if desired. These float-operated devices are subject to many errors including float lag, line shift, submergence of counter weight, temperature and humidity affecting measurements, and tape or wire stretch (Dalton et al., 1991). Typically, the smaller the float used, the greater the error potential. Most float devices were not designed to be used in small diameter wells (2-inches or less) and therefore are not often used in monitoring wells.

The buoyancy cylinder vibrating strip force transducer is also suited for measuring water-level changes in standard 2-inch monitoring wells. A vibrating strip force transducer system equipped with a 1.5-inch diameter buoyancy cylinder provides a precision of ±0.045 inches and can measure water level changes of 15 feet or less.

2.2.9 Ultrasonic Method

Ultrasonic devices measure the amount of time it takes for a sound wave to travel down a well casing, reflect off the water surface and return to the device. These devices use a microprocessor to transmit and receive multiple signals per second. This allows for rapid verification of readings. Models are available that can be placed on top of the well without ever lowering anything into it. This allows for rapid water level determination even in deep wells and reduces the potential of cross-contamination between wells.

Depending on the sophistication of the instrument, accuracy varies from ±0.02 to 0.1 foot. Well temperature gradients, joints, pumps, and other obstructions in a well can impede accuracy. An immiscible layer in a well may affect water level measurements. (Refer to Section 2.3.)

2.3 MEASURING AND SAMPLING IMMISCIBLE LAYERS

An immiscible layer may exist in a monitoring well either as a light non-aqueous phase liquid (LNAPL) or as a dense non-aqueous phase liquid (DNAPL). LNAPLs, also known as "floaters" or "floating free product," are relatively water-insoluble organic liquids (e.g., gasoline), are less dense than water (i.e., they have a specific gravity <1.0) and they typically spread on top of the capillary fringe and water table. **Figure 6** illustrates a LNAPL spill of diesel fuel and its distribution in an aquifer. Notice that the LNAPL tends to depress the capillary fringe and the water table.

DNAPLs, also known as "sinkers" or "sinking free product," are also relatively water- insoluble organic liquids (e.g., trichloroethylene), are more dense than water (i.e., the have a specific gravity >1.0) and typically migrate downward in an aquifer **Figure 7** illustrates a trichloroethylene (TCE)

DNAPL spill and its distribution in an aquifer. Notice that the mobile DNAPL in the bottom of the aquifer can actually travel in the opposite direction of groundwater flow if the right conditions exist. DNAPLs also tend to accumulate in low pockets on top of impervious layers existing in the aquifer.

2.3.1 Measuring Immiscible Layers

To measure the thickness of a LNAPL in a well, you typically use either a NAPL/water interface probe that distinguishes between water and NAPLs or a weighted tape coated with a water and non-water indicator substance. Interface probes are also available that can measure the thickness of DNAPLs.

Determining the difference between the LNAPL's "true" thickness in the aquifer and its "apparent" thickness in a water table well can be difficult **Figure 8** illustrates how different they can be. The apparent thickness is actually a sum of the LNAPL thickness in the capillary fringe, the true product thickness and the thickness of the LNAPL that is depressing the water table. Because of the difficulty in measuring the true product thickness, most investigators do not focus on it (Domenico and Schwartz, 1990). Investigators use apparent product thickness in a well as a relative measurement.

2.3.2 Sampling Immiscible Layers

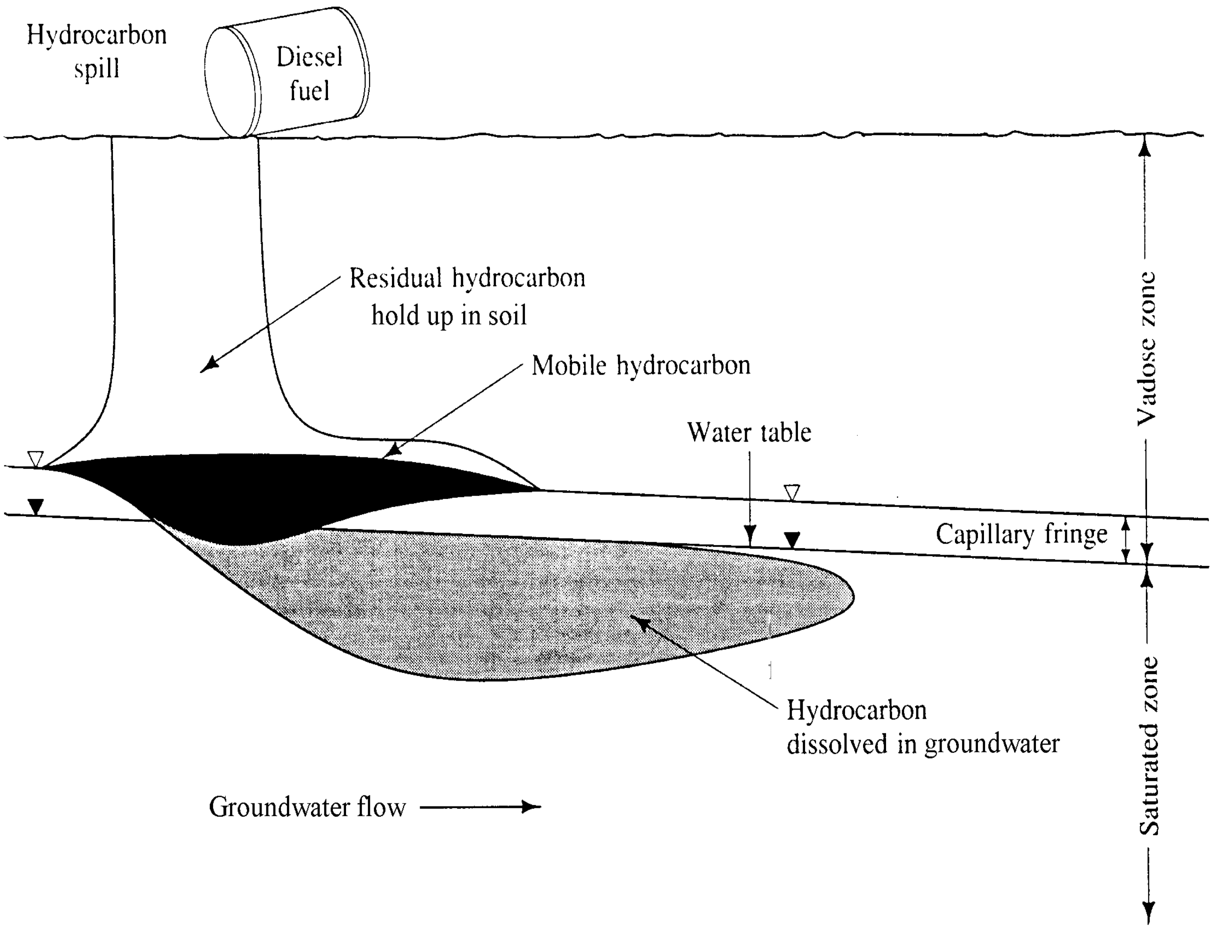
If you are collecting a LNAPL or a DNAPL sample from a well, do it before purging the well. Because a LNAPL or DNAPL usually exist in a well at a minimal thickness, a bailer is commonly used rather than a pump for collecting an immiscible layer sample.

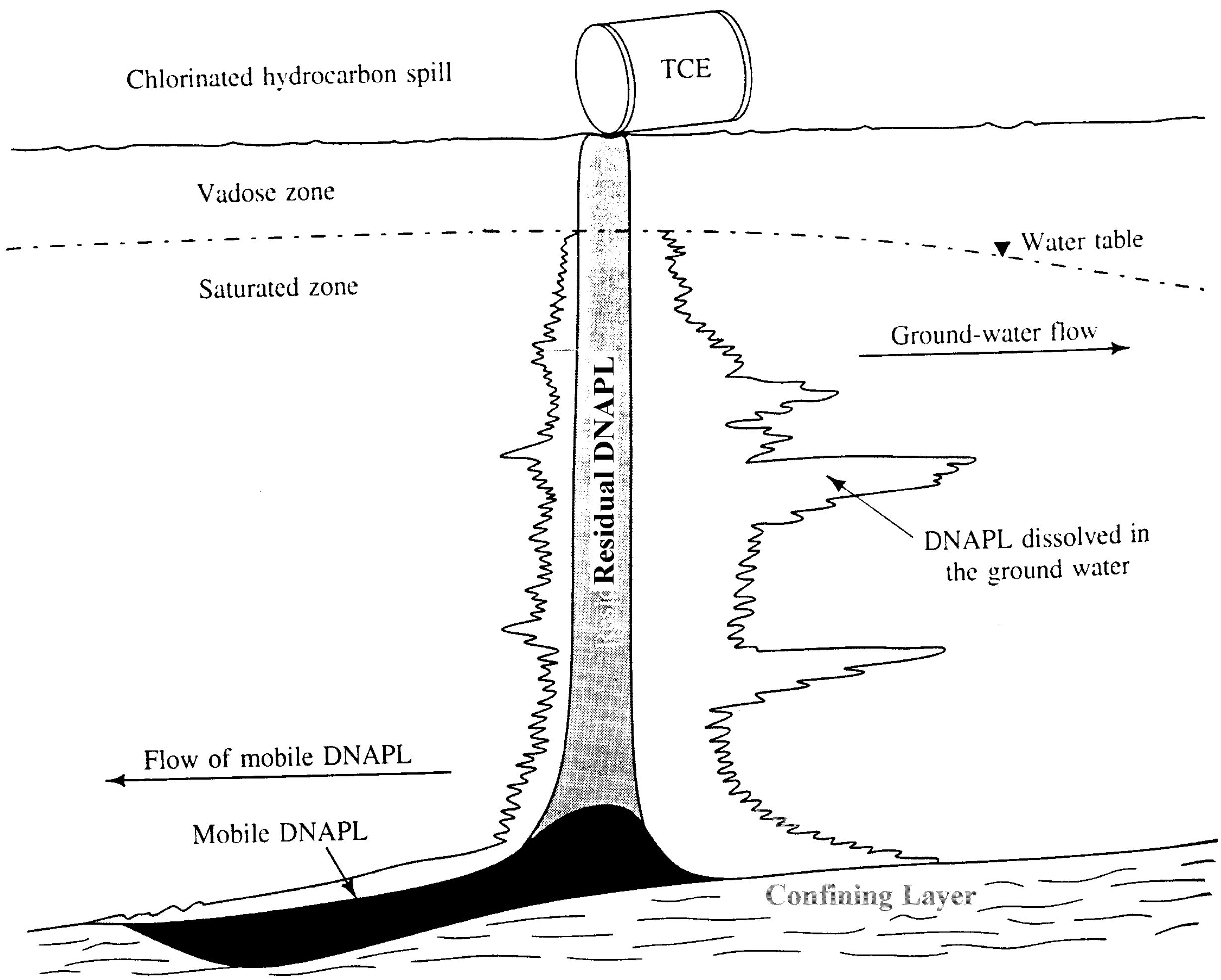
Refer to Section 2.3 of the *Groundwater Sampling Field Manual*, *PUBL-DG-038 96,* for specific procedures for measuring and sampling immiscible layers in water table wells and piezometers.

2.4 PURGING AND SAMPLING DEVICES

2.4.1 Technical Considerations

Table 3 provides operational and performance characteristics for a variety of commonly-used purging and sampling devices. This table can assist you with choosing appropriate purging and sampling equipment for a specific project. However, be cautioned that the operation and performance of a particular model of a device may vary from what is listed in this table. Reference the manufacturer's equipment and materials specifications and published literature on the performance of a specific model when evaluating its use, operation and performance.


Hydrocarbon
spill
Diesel
fuel
Residual hydrocarbon
hold up in soil
Mobile hydrocarbon
Water table
Capillary fringe
Vadose zone
Saturated zone
Hydrocarbon
dissolved in groundwater
Groundwater flow



Chlorinated hydrocarbon spill
TCE
Vadose zone
Water table
Saturated zone
Ground-water flow
Residual DNAPL
DNAPL dissolved in the ground water
Flow of mobile DNAPL
Mobile DNAPL
Confining Layer

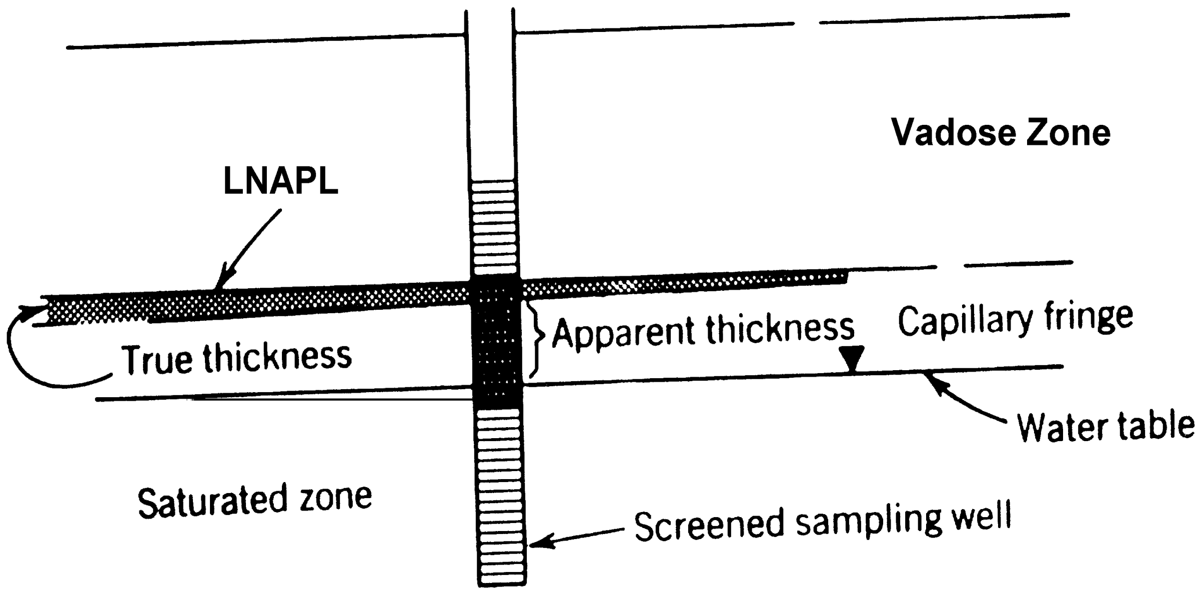

Vadose Zone
LNAPL
True thickness
Apparent thickness
Capillary fringe
Water table
Saturated zone
Screened sampling well

TABLE 3: Generalized Characteristics of Common Purging and Sampling Devic

	Device	Maximum Sample Depth	Minimum Well Diameter	Range of Flow Rate or Volume	Ability to Control Flow Rate	Sensitive Sample Alteration	Eas Transp Set
P O S I T I V E D I S P L A C E M E N T	**Centrifugal submersible pump (low-flow)**	~ 90 meters ~ 300 feet	4.45 cm. 1.75 in.	0.1- 30 L/min 0.03 - 8 gpm	Good if flow controller used	Low	Requir genera set
	Bladder pump (low-flow)	305 meters 1000 feet	3.8 cm. 1.5 in.	0 - 11 L/min 0 - 3 gpm	Good if flow controller used	Low	Bul transp set

	Progressive cavity (helical-rotor) pump (low-flow)	50 meters 160 feet	5 cm. 2 in.	0.1 - 6 L/min 0.03 - 1.5 gpm	Good with rheostat	Low to moderate	Bulk se
	Gear-drive pump (low-flow)	60 meters 200 feet	5 cm. 2 in.	0 - 6 L/min 0 - 1.5 gpm	No	Probably low to moderate	E
	Piston pump (gas-drive)	275 meters 900 feet	3.8 cm. 1.5 in.	0 - 6 L/min 0 - 1.5 gpm	Highly variable	Variable	Ea diff
	Gas-displacement or air-displacement pump	90 meters 300 feet	2.5 cm. 1 in.	0.5-38 L/min 0.1-10 gpm	Variable	Moderate to high	Moc
	Piston pump (manual)	Variable	2.5 cm. 1 in.	Variable	Variable	Moderate to high	Ea diff

Table 3 continued on next page

TABLE 3 (continued)

	Device	**Maximum Sample Depth**	**Minimum Well Diameter**	**Range of Flow Rate or Volume**	**Ability to Control Flow Rate**	**Sensitive Sample Alteration**	**Ea Transp Se**
G R A B	**Open bailer**	No limit	1.3 cm. 0.5 in.	Variable but typ. < 8 L/min typ. < 2 gpm	Use bottom emptying device	Low to high	V e
	Point-source		1.3 cm.	Variable but typ. < 8 L/min	Use bottom emptying	Low to	V

	bailer	No limit	0.5 in.	typ. < 2 gpm	device	high	ea
	Syringe sampler	No limit	3.8 cm. 1.5 in.	0.04-0.8 L/min 0.01-0.2 gpm	Variable	Moderate to high	Moc
SUCTION	**Peristaltic pump**	8 meters 25 feet	1.3 cm. 0.5 in.	0.04-30 L/min 0.01 - 8 gpm	Good	Variable	E.
	Surface centrifugal pump	8 meters 25 feet	2.5 cm. 1 in.	4 - 95 L/min 1 - 25 gpm	Highly variable	Very high	Moc
OTHERS	**Inertial lift pump**	60 meters 200 feet	2.5 cm. 1 in.	0 - 8 L/min 0 - 2 gpm	Variable	Moderate	Moc
	Gas-lift or air lift pump	Variable	2.5 cm. 1 in.	Variable	Variable	Very high	Moc

Sources: Parker (1994), Pohlmann and Hess (1988), U.S. Environmental Protection Agency (1993), U.S. Environmental
et al. (1991).

Operation, Service, Reliability and Durability

Easy operation and servicing, plus the reliability and durability of a piece of equipment are important considerations for choosing purging and sampling equipment. The equipment should be easy to operate, decontaminate and service in the field. The more mechanically simple the device and its accessories, the less chance it will malfunction and the easier it will be to operate and service in the field. If a well is located in a remote area not accessible by a vehicle, the equipment's portability can be very important.

Proper training on equipment operation, maintenance and service is essential to ensure top quality samples. If the equipment is not operated and maintained properly, sample quality will suffer.

Time and Cost

Consider the time it takes to operate, decontaminate and transport a piece of equipment during selection. Initial capital cost, and operation and maintenance costs are also important considerations; however, ***do not compromise data quality to save time and cost*** Choose equipment that meets data quality objectives and will not change the physical and chemical composition of your samples. Selecting equipment based on cost and time savings alone can be far more expensive in the long run if the equipment yields false positive or false negative analytical results; malfunctions often; is difficult to use and service; provides data that does not meet regulatory and data quality objectives; or provides data that does not stand up to legal scrutiny.

Dedicated purging and sampling equipment - case studies

Meyer (1990) and Parker et al., (1992), have shown that using dedicated groundwater sampling equipment (devices "permanently" left in a well) may save time and money over using non-dedicated systems. In addition, dedicated equipment consistently collects high-quality samples. Both studies indicated that, although there was a high initial capital cost in purchasing the dedicated equipment, the systems paid for themselves in about three years.

Meyer (1990) conducted a three-year study comparing the technical and economic benefits of using dedicated and non-dedicated systems at the Weldon Spring Site – a 12-year, $400 million remedial action project in east central Missouri. Meyer's study used 33 dedicated bladder pumps in 33 of the 100 monitoring wells installed at the site. Sampling with the dedicated bladder pumps equated to a labor cost savings of $160 per well per year (based on $40/hr. labor) compared to the non-dedicated sampling systems. The dedicated bladder pumps provided an additional cost savings because decontamination quality assurance samples (i.e., field blanks) were not required. This garnered a savings of approximately $60 per well per year. Additional "hidden" economic benefits included fewer days spent in the field, less money spent on per diem expenses and, because less time was spent in the field, more time was available to work on other projects.

Parker et al., (1992) conducted a study comparing the technical and economic benefits of using dedicated low-flow submersible pumps and disposable bailers at the Union Pacific

Railroad Yard superfund site in Sacramento, California. Parker's study evaluated the use of disposable bailers vs. dedicated Grundfos Redi-Flo2® submersible pumps installed in nine monitoring wells. Ninety samples were collected from the nine wells using the dedicated pumps and disposable bailers. Samples were collected quarterly from each well and analyzed for VOCs. Comparison of labor costs for sampling indicated an approximate cost savings of $100 per well per sampling event using the dedicated pumps vs. the disposable bailers. Annual labor cost savings were projected to be $12,000 if dedicated pumps are installed in all of the site's 42 monitoring wells. Costs of the dedicated pumps were projected to be recovered in approximately three years due to labor cost savings.

Cost savings for both studies were realized due to reduced time for equipment setup, sampling and removal; virtual elimination of decontamination procedures; and a reduction in the number of quality assurance samples required. Equipment replacement or repair costs due to continued insertion and removal and decontamination associated with non-dedicated equipment were eliminated. The quality of data collected with dedicated pumps was very high because the wells were purged at consistent depths and flow rates and the potential for cross-contamination between wells was greatly reduced. Quality assurance audits for Meyer's study went smoothly using dedicated equipment and its use helped eliminate numerous uncertainties regarding sample quality typical of non-dedicated equipment.

Materials

The materials that purging and sampling equipment are made of can adversely affect sample quality. The choice of equipment materials should be based on: 1) the chemistry of the groundwater in the well (e.g., low pH, high dissolved oxygen, hydrogen sulfide, dissolved solids, high carbon dioxide and high chloride); 2) the type, form (i.e., dissolved or free product) and concentration of contaminants in the well; 3) whether the equipment's materials may leach or sorb contaminants; and 4) whether the equipment's material may degrade or otherwise change the chemical composition of samples by physical, chemical and biological processes.

Parker (1992) provides an excellent discussion and literature review of several commonly available materials and their resistance to chemical attack, sorption of metals and organics and leaching of metals. Parker (1992) focuses on Teflon®, PVC and stainless steel used in samplers and well casing materials.

Common materials used in purging and sampling equipment include (from most inert to least): polytetrafluorethylene (PTFE), commonly available as Teflon®; rigid polyvinyl chloride (Type I PVC); flexible polyvinyl chloride (Type II PVC); stainless steel (#304 and #316); Viton®; polyethylene; polypropylene; acrylonitrile butadiene styrene (ABS); low-carbon steel; galvanized steel; carbon steel; and silicone rubbers. Teflon®, rigid PVC and stainless steel are the most commonly used and the most inert materials. Table 4A and 4B lists the relative inertness (i.e., ability to adsorb or leach contaminants and resistance to chemical reaction and degradation) of several rigid and flexible materials. Tables 4A and 4B are arranged so the most inert material is listed first and the least inert material is listed last.

Table 4A: Relative Inertness of Rigid Materials
(After Nielsen & Yeates, 1985 and Parker, 1992)

Teflon® (polytetrafluoroethylene, PTFE)
Stainless steel 316
Stainless steel 304
Polyvinylchloride (PVC)
Low-carbon steel
Galvanized steel
Carbon steel
Brass

Table 4B: Relative Inertness of Flexible Materials
(After Nielsen and Yeates, 1985)

Teflon® (polytetrafluoroethylene, PTFE)
Polypropylene
Flexible PVC/Linear polyethylene
Viton®
Conventional polyethylene
Tygon®
Silicone/Neoprene

<u>Sample tubing - case study</u>

Barcelona et al., (1985), conducted laboratory sorption experiments for five flexible tubing materials (Teflon®, polyethylene, polypropylene, polyvinylchloride (PVC) and silicone rubber) to determine sorption bias of chloroform, trichloroethylene, trichloroethane and tetrachloroethylene. Results of the experiments showed that all five materials sorbed the test compounds under short exposure periods; however, Teflon® showed the least adsorption and leaching problems followed by polypropylene, polyethylene, PVC and silicone rubber, which exhibited the worst adsorption and leaching problems.

2.4.2 Grab Samplers

Grab samplers collect a sample at a discrete depth in a well without the sample being pumped or being lifted to the surface by a gas or by air. Typical grab samplers include bailers, syringe samplers and thief samplers. You lower these devices into a well by rope, cable or tubing to collect a sample at a discrete depth. You can use bailers for both purging and sampling a well. Most other grab samplers are designed for sampling only.

Bailers

Two common styles of bailers include the single check valve or "standard" bailer and the dual or double check valve bailer, also known as the point-source bailer. Point-source bailers may reduce mixing of the sample with the water column as the bailer is removed from the well.

Some researchers have shown bailers capable of collecting high quality samples (e.g., Baerg et al., 1992; Imbrigiotta et al., 1988); however, researchers have cautioned that the quality of samples collected with bailers (and disturbance of fines around the well during purging) ***highly depend*** on the skill, care and consistency of the operator using the bailers. Some researchers believe that bailers are inappropriate for collecting substances such as VOCs and redox-sensitive trace metals (Houghton and Berger 1984; Yeskis et al., 1988; Stolzenburg and Nichols 1985) because bailers can change sample chemistry, cause contaminant loss and increase sample turbidity. Imbigiotta et al. (1988), Muska, et al. (1986), Yeskis (1988) and other researchers have found that bailers tend to have the greatest variability in VOC results (low precision) compared to other common sampling devices (e.g., bladder pump, submersible pump, peristaltic pump, etc.,).

Bailers are effective for collecting stable substances not affected by sample aeration or changes in a sample's redox state (e.g., chloride).

WDNR conducted a study between 1994 and 1995 to evaluate differences in VOC analytical results attributable to samples collected with a Teflon® bailer equipped with a bottom-emptying device and samples collected with a portable (non-dedicated) Keck® helical-rotor pump operated at low-flow pumping rates (< 500 ml/min). Nine monitoring wells that had a history of VOC contamination were sampled at three landfills. Only small differences in VOC analytical results were found between samples collected with the bailer and samples collected with the low-flow pump. The small differences in VOC analytical results could not be attributed to the use of the equipment or the purging and sampling procedures. Great care was taken to slowly and gently lower and raise the bailer in and out of the water column. A pulley was used to lift the bailer straight up and out of the well and a bottom-emptying device was used to decant samples to their respective VOC vials.

The study recommended: 1) using a bailer equipped with a bottom-emptying device or a low-flow pump for collecting VOC samples from monitoring wells; 2) using a bailer at sites where wells are not easily accessed; 3) using a bailer for sampling on days below 20°F; and 4) using a dedicated system if a low-flow pump is used to collect samples. On average, it took four times longer to collect samples with the portable low-flow pump than with the portable bailer: The portable low-flow pump is heavier and bulkier; includes more equipment and accessories (e.g., power source, pump and sample tubing, flow-through cell, etc.), and takes longer to set up, decontaminate and dismantle.

Design and Materials

Figure 9 illustrates a variety of bailers and bottom-emptying devices. Bailers come in a wide variety of styles, lengths, diameters and materials. They are typically 3 to 7 feet (1 to 2 meters) but may be constructed to almost any length. Common materials used in constructing bailers include high grade stainless steel, rigid PVC and various fluorocarbon materials such as Teflon®. Bailers should be made of relatively inert materials that will not sorb contaminants onto the bailer or leach contaminants out. The same holds true for choosing bailer rope or cable. Polypropylene or nylon rope, stainless steel cable, or Teflon®-coated wire are good choices under most conditions. If you use cotton or other sorptive rope or cable, discard it after a single use or cut off and dispose of those portions that touched any contamination.

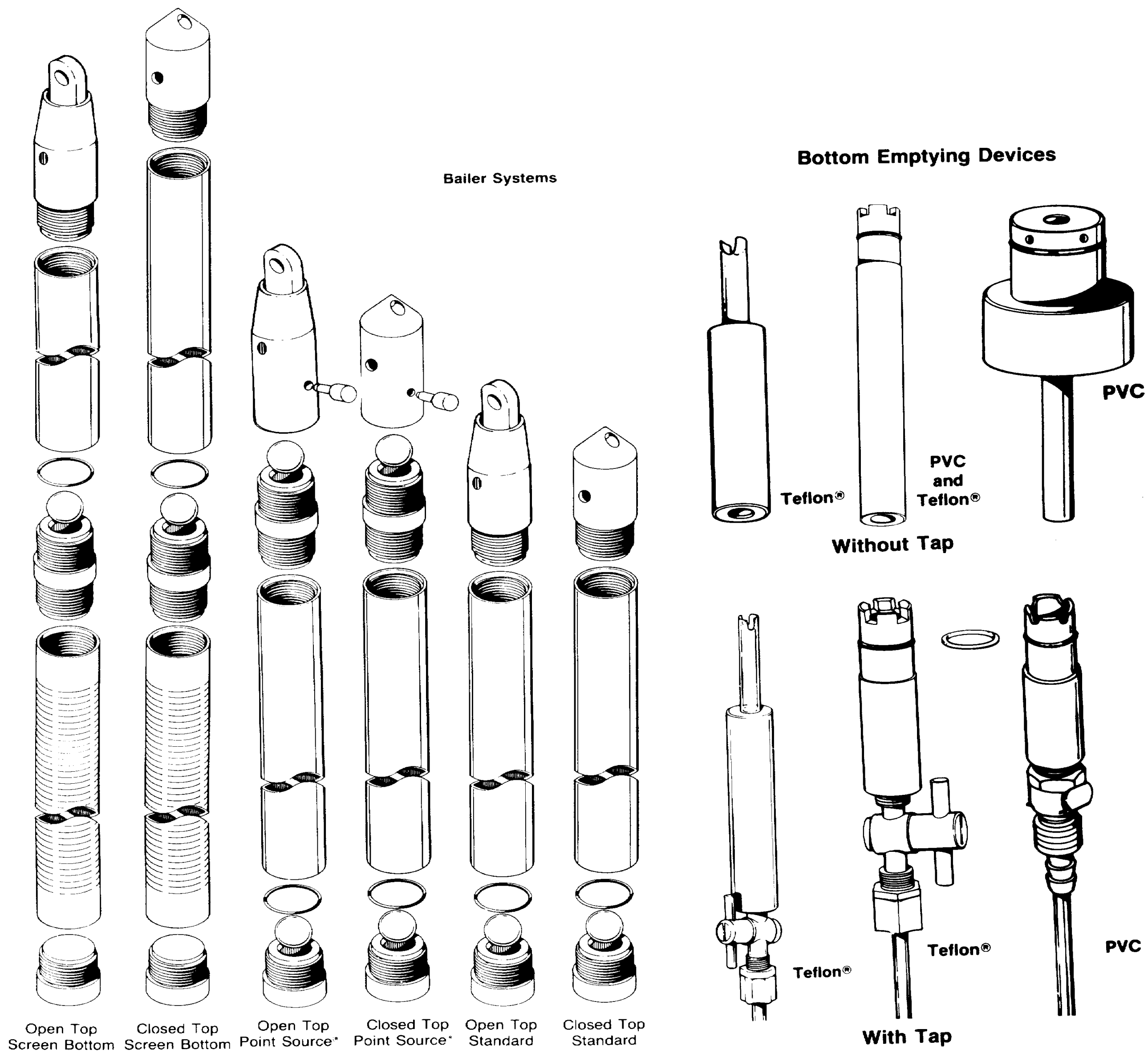


Figure 9: Bailer system and botem emptying devices. (Diagrams courtesy of TIMCO™)

Operation

A bailer is essentially a hollow rigid tube that fills from the bottom up as you lower it into the water column. You attach a bailer to a line or cable and slowly lower it into the water column. Slowly lowering and raising the bailer is essential to minimize sample turbulence, agitation, degassing, aeration and turbidity. ***NEVER*** let a bailer free-fall into the water and ***NEVER*** rapidly raise the bailer out of the water column! These activities severely agitate the samples collected from the well. In addition, these activities may over-develop the well or damage the well's filter pack.

After slowly raising the bailer out of the water column, lift it straight up and avoid banging it against the casing wall. To accomplish this, you can place a tripod and pulley over the well or use vertical hand-over-hand lifting. The bailer lifting method known as "helicoptering," or grabbing the rope with alternating horizontal hands, causes the bailer to bounce from side to side within the well casing. This can cause sample agitation, the gain or loss of dissolved gasses in the sample, and loss of VOCs by volatilization.

To avoid sample aeration, use a bottom emptying device when decanting samples from a bailer. Pouring the sample from the top of a bailer is unacceptable under most circumstances due to excessive sample agitation and aeration.

Advantages of bailers

- Can be constructed of almost any material.
- Relatively inexpensive to purchase or construct.
- Simple to operate and durable with few parts to break.
- No depth or well diameter limitations.
- Light, portable and easy to disassemble and decontaminate in the field.
- Requires no power source or controller box.
- Ideal for collecting samples on days when the temperature is below freezing.

Limitations of bailers

- May lose VOCs or alter redox-sensitive samples.
- May artificially mobilize colloids and particulates near the well screen during its operation.
- Sample quality **highly** depends on the skill and care of the bailer's operator.
- Time consuming and labor intensive, especially for deep wells and wells requiring purging of many well volumes.
- Check valve ball may leak when collecting silt- or sand-laden samples.
- Direct, in-line filtration is possible but may be time consuming.
- Heavy use of a bailer may cause the bailer's surface materials to become rough and scratched, which makes it difficult to properly decontaminate the bailer.

Syringe Samplers

You can use these devices at any depth and thus sample at discrete depths. Syringe samplers cannot be used to purge a well. Samples collected with a syringe device do not contact atmospheric gases, are subject to very slight negative pressure and therefore, neither aeration nor degassing of samples should occur (Herzog et al., 1991). However, Imbrigiotta et al., (1988) found that the syringe sampler had poor recovery of VOCs in comparison to six other sampling devices.

Design and Materials

A variety of designs for syringe samplers are available on the market. Most work with a moveable plunger, piston, or float mechanism operated mechanically, pneumatically or by hydrostatic pressure. Common materials used in the construction of syringe samplers include flexible tubing, stainless steel ballasts and tubes and PVC or polyethylene syringe chambers. As with any other sampling device, make sure that the design, operation and material of the device do not adversely affect the samples being collected.

Operation

Syringe samplers function much like a medical syringe. After you lower the device into a well's water column, a plunger or piston is pulled up either mechanically or pneumatically, thus allowing water to enter the lower sample chamber. After the piston rises to the top and the sample chamber is full of water, pull the device to the surface and decant it into sample containers.

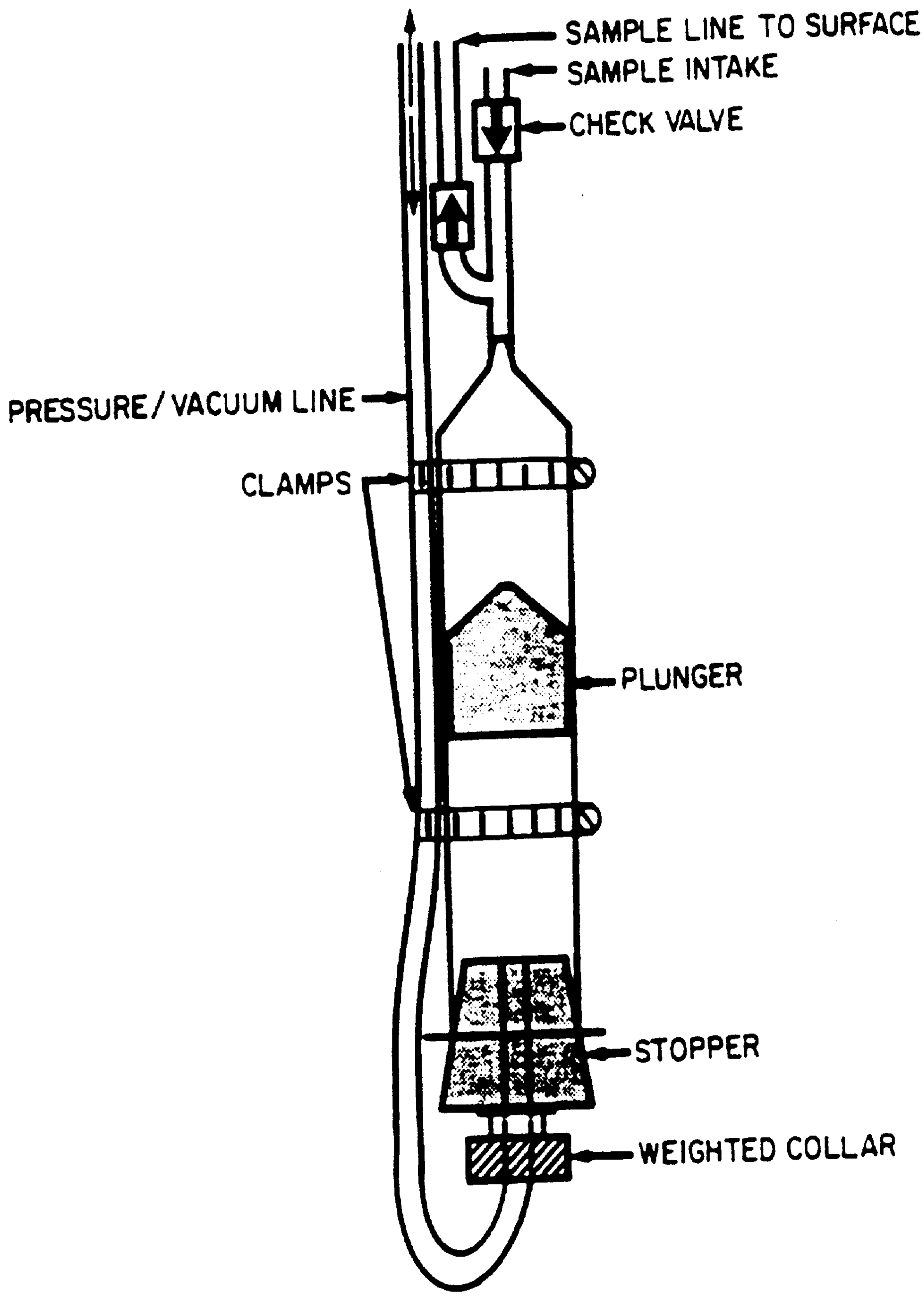
Modifications to the syringe sampler allow it to become a simple syringe pump (**Figure 10**). It is, therefore, no longer a grab sampler. Alternating vacuum and pressure drive the piston or plunger up and down. The intake port may be faced upward to ensure that any gas in the sample chamber is released before sample collection. A pair of check valves, one below the sample intake and one on the sample line, allows the sample to be drawn in under vacuum and then flow to the surface through a separate line after pressure is applied to the piston. The main advantage of the syringe pump over the syringe sampler is that the pump allows you to collect unlimited sample volume without pulling the device from the well.

Advantages of syringe samplers

- Can be made of a wide variety of readily available materials.
- Relatively inexpensive to purchase or construct.
- Usually simple to operate and requires little operator training.
- Most have no depth limitations.
- Effective at collecting depth-discrete samples.
- Light and portable and usually easy to decontaminate in the field.
- Typically requires no power source (some syringe pumps may require an air compressor or electrical power source).

Limitations of syringe samplers

- Plungers may be prone to bind and leak, especially when collecting silt-laden samples.
- Operation may be difficult if the device is lowered into a deep well.


SAMPLE LINE TO SURFACE
SAMPLE INTAKE
CHECK VALVE
PRESSURE/VACUUM LINE
CLAMPS
PLUNGER
STOPPER
WEIGHTED COLLAR

- Plungers are typically made of non-inert materials (rubber) unsuitable for VOCs and other sorptive contaminants.
- Sample transfer can be difficult.
- Degassing can occur while samples are being decanted.
- Syringe chambers usually have limited sample volume.
- Not widely available through commercial markets.

Other Grab Samplers

Other, less common grab samplers include the pressurized bailer, the Chismar® (surface bomb/pressurized bailer) samplers, the Westbay® sampler and the VOA trap sampler.

Thief samplers such as Kemmerer®, Van Dorn® and alpha bottle samplers are also grab samplers but are not commonly used or appropriate for groundwater sampling, although they are widely used for discrete-depth surface water sampling.

2.4.3 Suction-lift Pumps

Suction-lift pumps, especially surface centrifugal pumps, are considered unacceptable for collecting VOCs, dissolved metals, pH, Eh and other gas-sensitive or volatilizing substances or measurements. The vacuum applied on the sample during collection may cause degassing. Suction-lift pumps are considered acceptable for collecting major and minor ions that are not gas-sensitive (refer to Section 2.6.7). Peristaltic and surface centrifugal pumps are two common types of suction lift pumps. Of these two suction-lift pumps, the peristaltic pump is far less likely to adversely affect samples compared to surface centrifugal pumps.

As suction-lift implies, these pumps work by creating a vacuum or suction (in the sampling tube) that pulls groundwater to the surface. In theory, suction-lift pumps should be able to lift water up to 32 feet (9.7 meters); however, in practice, anywhere from 15 to 25 feet (4.6 to 7.6 meters) is the upper limit of their effectiveness. Pumping rates for suction-lift pumps typically range from 0.03 to 15 gallons per minute (gpm) or 0.1 to 57 liters per minute (L/min). Peristaltic pumps commonly have the lower pumping range (0 to 8 gpm or 0 to 30 L/min) while surface centrifugal pumps have pumping rates as high as 40 gpm (150 L/min).

Peristaltic Pumps

Barker and Dickhout (1988) conducted laboratory research to evaluate the loss of volatile organic analytes from groundwater charged with dissolved gasses such as methane and carbon dioxide. A positive displacement bladder pump (Well Wizard®, QED, Inc.), inertial-lift pump (WaTerra® pump) and peristaltic pump were employed in sampling methane-charged groundwater from a monitoring well for volatile aromatic hydrocarbons and CO_2-charged water reservoir (i.e., an artificial laboratory well) spiked with known concentrations of volatile chlorinated hydrocarbons. In both the field and laboratory cases, the peristaltic pump provided samples with a significant negative bias (9 to 33 percent lower) relative to the bladder pump and inertial-lift pump methods.

Baerg et al., (1992) conducted laboratory research to evaluate the loss of volatile organic compounds (VOCs) caused by the sampling method used. Several devices (peristaltic pump, stainless and

Teflon® bailers, VOA trap sampler, bladder pump, inertial-lift pump and double valve sampler) were used to collect samples for VOCs from a laboratory monitoring well. VOC analytical results for the peristaltic pump were 7 percent to 12 percent lower than the control VOC concentrations. The inertial-lift pump performed the worst with VOC results up to 34 percent less than the control.

Imbrigotta et al., (1988) conducted a field evaluation of seven sampling devices for purgeable organic compounds (POCs) in groundwater. One of the devices tested was a peristaltic pump outfitted with Teflon® tubing and a glass Erlenmeyer receiving flask for sample collection. It was pumped at 600 ml/min (0.6 L/min) or less. Of the seven devices tested, the peristaltic pump consistently recovered lower POC concentrations than the other devices and had the lowest precision of the four pumps tested (gear submersible, bladder, helical-rotor and peristaltic pumps); however, it had a greater precision than all three grab samplers tested (syringe, open bailer and point-source bailer).

Tai et al., (1988) found good recoveries of VOCs under lab conditions using a peristaltic pump outfitted with Teflon® tubing and used under low lift conditions – 5 feet in this case.

In general, the lower the lift, the lower the pumping rate, and using non-sorptive tubing such as Teflon® will minimize the effects a peristaltic pump may have on a sample.

<u>Operation and Materials</u>

Peristaltic pumps are very easy to use. The sample tubing is usually 1/4 inches in diameter and open at both ends. Some kinds of flexible tubing (e.g., silicone and Tygon®) can leach plasticizers and sorb organic compounds that may adversely affect sample quality.

Place the suction end of the tube into the well to the desired depth. Place the discharge end in the sample container. You can attach a transfer vessel, a filtering device chamber or an in-line filter directly to the pump's discharge tubing. This is the recommend filtering method. Rotating two or more rollers along the sample tubing causes a vacuum on the tubing, thus lifting the water out of the well. Decontamination usually consists of running a detergent or disinfectant through the sampling tube, followed by appropriate decontamination rinses.

<u>Advantages of peristaltic pumps</u>

- Allows for easy, direct in-line filtration of samples.
- Portable, easy to use and little operator training is required.
- Readily available and relatively inexpensive.
- Variable flow rates are possible.
- Sample does not contact pump parts.
- Durable and reliable.
- Can be used in wells of any diameter.

<u>Limitations of peristaltic pumps</u>

- Requires a power source.
- Vacuum may cause volatilization and degassing in gas-sensitive or volatile samples.

- Lift restriction of 25 feet (8 meters) or less.
- Flexible sample tubing (e.g., silicone and tygon) may leach placticizers and adsorb or desorb organic compounds.
- Field repair may be difficult.

Surface Centrifugal Pumps

Surface centrifugal pumps are commonly used for well development. High pumping rates, sample alteration and sample contact with pump parts makes these devices unacceptable for most well monitoring and sampling applications. Do not use these pumps for collecting groundwater samples from monitoring wells.

Advantages of surface centrifugal pumps

- Can purge large volumes of water quickly.
- Easy to use and operate.
- Readily available.

Limitations of surface centrifugal pumps

- Difficult to adequately decontaminate.
- Generally unacceptable for collecting groundwater samples.
- Pump parts come into contact with sample.
- Lift restrictions limit effective purging and sampling depth to 20 feet (6 meters).
- Require a power source, usually an electric outlet or portable generator.
- High pumping rates may over-develop a well.
- May require priming before pumping.

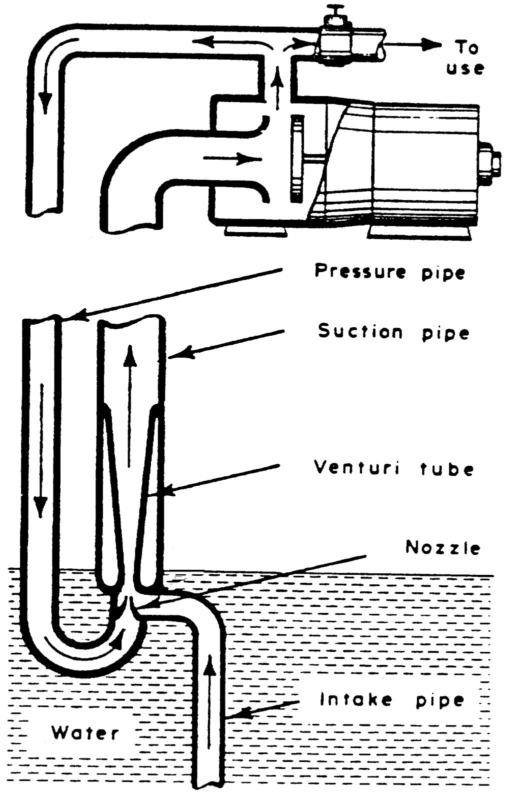
Other Suction-lift Pumps

Other common suction-lift pumps include manual diaphragm-type pumps, pitcher pumps and eductor or jet pumps. These pumps are not typically used and are inappropriate for sampling monitoring wells. **Figure 11** illustrates these three pump types.

Manual Diaphragm and Pitcher Pumps

The manual diaphragm ("guzzler") pump consists of a lever-powered flexible diaphragm between 2 check valves. They are commonly self-priming to 20 feet (6 meters) and capable of moving considerable volumes of water. However, they are not acceptable for either purging or sampling monitoring wells. These pumps are difficult to decontaminate properly.

The pitcher pump is used for shallow water supply wells. Pitcher pumps apply a suction to a well's casing by a lever-operated piston and barrel mechanism. Pitcher pumps should not be used to collect groundwater samples; however, if you are interested in what contaminants a consumer of pitcher pump water may be exposed to, then you may collect groundwater samples from this type of pump. The pump's flow rate should be kept as low as possible during sampling.


To use
Pressure pipe
Suction pipe
Venturi tube
Nozzle
Intake pipe
Water

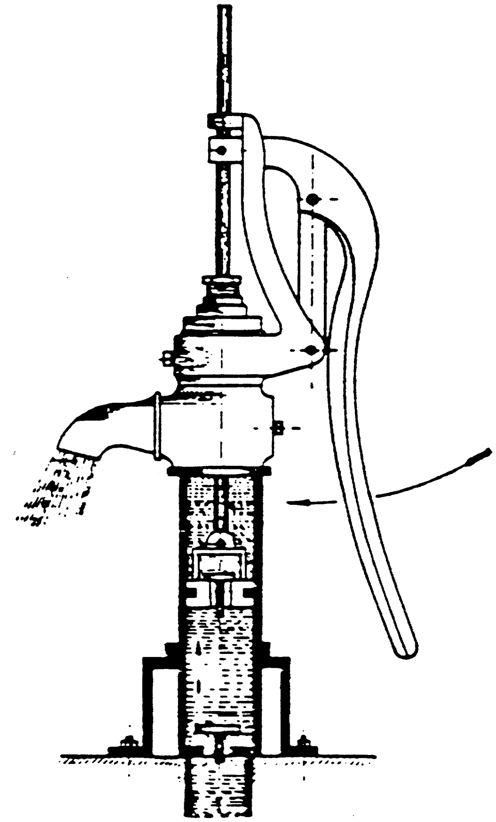
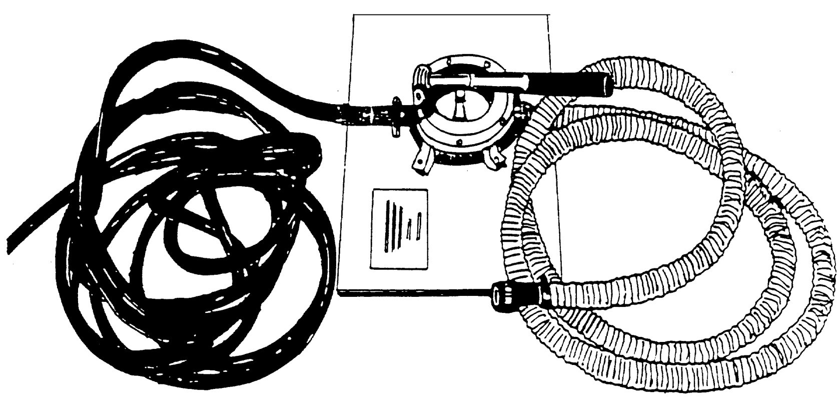


Figure 11: Suction-lift punps: a) jet pump, upper left; b) pitcher pump, upper right; and c) manual diaphragm pump, bottom.



Jet or Eductor Pumps

A jet or eductor (venturi) pump is commonly used for water supply wells; however, this pump is only suitable for developing and purging monitoring wells. The operation of a jet or eductor pump causes a large pressure drop in the water passing through these pumps. Therefore, they should not be used for collecting gas-sensitive or VOC samples. These pumps are usually very bulky and require priming before they will operate.

2.4.4 Centrifugal Submersible Pumps

In the past, centrifugal submersible pumps, or impeller-driven pumps, were primarily designed for use in water supply wells. Recently, manufacturers have offered several models that work well for both the purging and sampling of 2-inch diameter monitoring wells. Centrifugal submersible pumps are categorized as a positive displacement device.

Design and Materials

A centrifugal submersible pump consists of impellers or vanes that are spun or rotated by a sealed electric motor. Pumps designed for 2-inch monitoring wells are usually cooled and lubricated with water rather than with hydrocarbon-based coolants and lubricants that could contaminate groundwater samples.

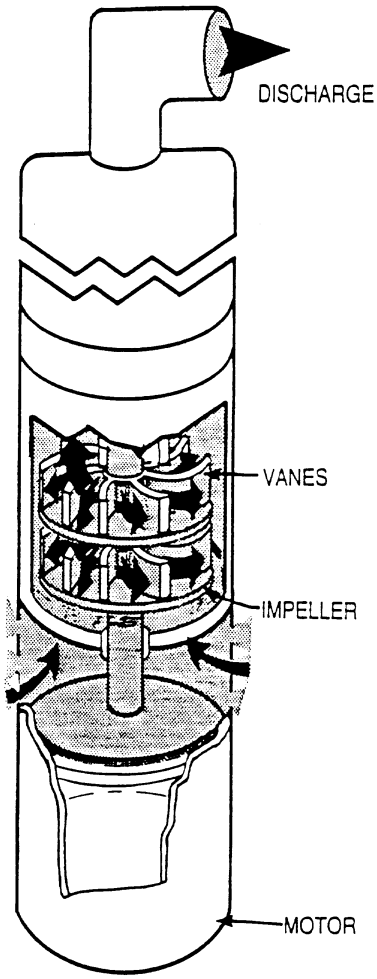
These pumps can be fabricated of stainless steel, PTFE (Teflon®), Viton® and other non-sorptive materials appropriate for collecting VOCs and other sensitive parameters. Pumps are now available that can achieve variable flow rates and flow rates as low as 100 ml/minute (0.1 L/min or 0.03 gpm). Several commercially available pumps capable of achieving low-flow rates are available for 2-inch monitoring wells.

Operation

Centrifugal submersible pumps operate by spinning or rotating an impeller or series of impellers that cause water to be accelerated outward and then upward into the pump's discharge line. **Figure 12** illustrates the movement of the impellers and water in this type of pump. The higher the pumping rate, the greater the potential for sample alteration by sample agitation, increased turbulence and pressure changes in the sample. Consider using a variable-speed pump when purging and sampling monitoring wells.

A centrifugal submersible pump is usually suspended in a monitoring well by its water discharge line, a support cable, or both. These pumps can be dedicated to above ground or flush mount wells (see Figure 12), thus eliminating the need to transport, set-up and decontaminate the pump. Dedicated pump systems also eliminate the need to collect quality assurance field blank samples.

Low-flow centrifugal submersible pumps appear to perform similarly to low-flow bladder pumps in preserving sample integrity during the well purging and sampling process.


DISCHARGE
VANES
IMPELLER
MOTOR

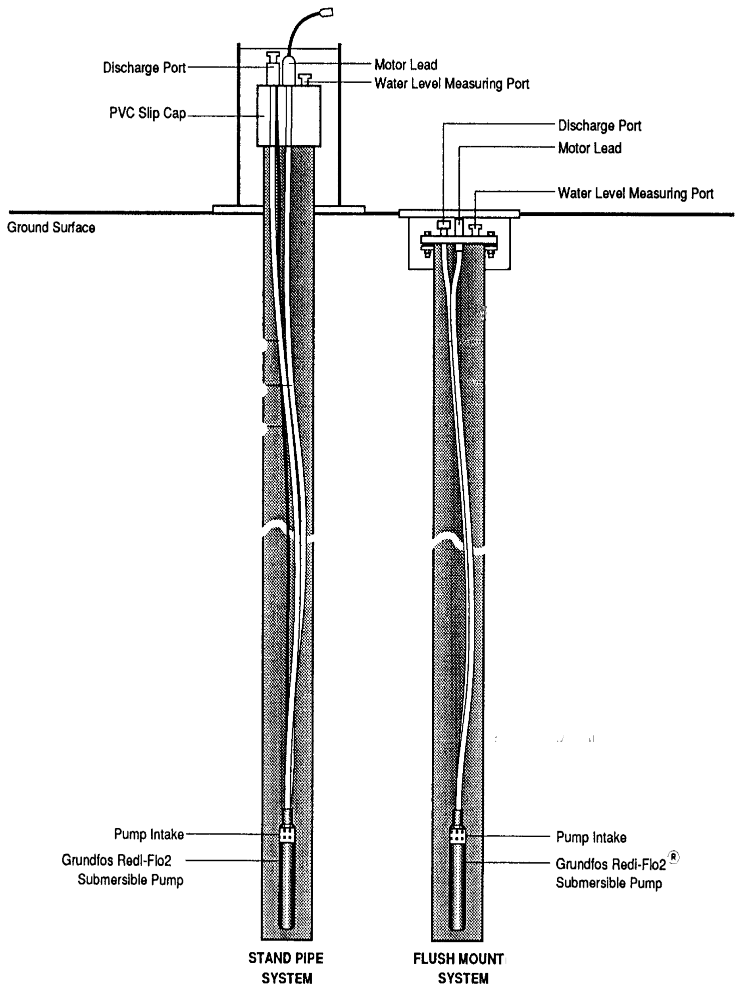

Discharge Port
Motor Lead
Water Level Measuring Port
PVC Slip Cap
Discharge Port
Motor Lead
Water Level Measuring Port
Ground Surface
Pump Intake
Grundfos Redi-Flo2
Submersible Pump
Pump Intake
Grundfos Redi-Flo2®
Submersible Pump
STAND PIPE
SYSTEM
FLUSH MOUNT
SYSTEM

Figure 12: Centrifugal submersible pump: a) functional diagram, left (Courtesy of Grundfos Pumps Corp.); b) stand pipe and flush mount systems, right (Parker et al, 1992).

Advantages of centrifugal submersible pumps

- When low-flow pumping rates are used, these pumps consistently collect high quality samples.
- Motor is sealed from impellers thus protecting against contaminating the samples.
- Capable of variable flow rate (typ. 0.1 - 30 L/min or 0.03 - 8 gpm).
- May collect low turbidity samples (< 5 NTUs) when low pumping rates used.
- Moderate to high lift capability, approximately 300 feet (90 meters).
- Initial high capital cost may be recovered if dedicated pumps are used.
- Priming is not necessary.
- Models are available that are constructed of relatively inert materials.
- Allows for easy, direct in-line filtration of samples.

Limitations of centrifugal submersible pumps

- Models not capable of low-flow rates are not suited for collecting gas-sensitive and VOC samples.
- Requires external power source - portable systems usually require a heavy generator typically powered by gasoline (potential extraneous contaminant source).
- Some variable speed models must be started at high flow rates initially.
- Purging and sampling from deep wells may be slow.
- Relatively time consuming to disassemble and decontaminate.
- Portable but may be bulky, heavy and difficult to transport over long distances and over rugged terrain.
- Portable systems may freeze up in winter during sampling and decontamination.
- Transport, setup and decontamination time is high compared to bailers if the pump is not dedicated to the well.
- Motor may slightly heat the samples.

2.4.5 Progressive Cavity (helical-rotor) Pumps

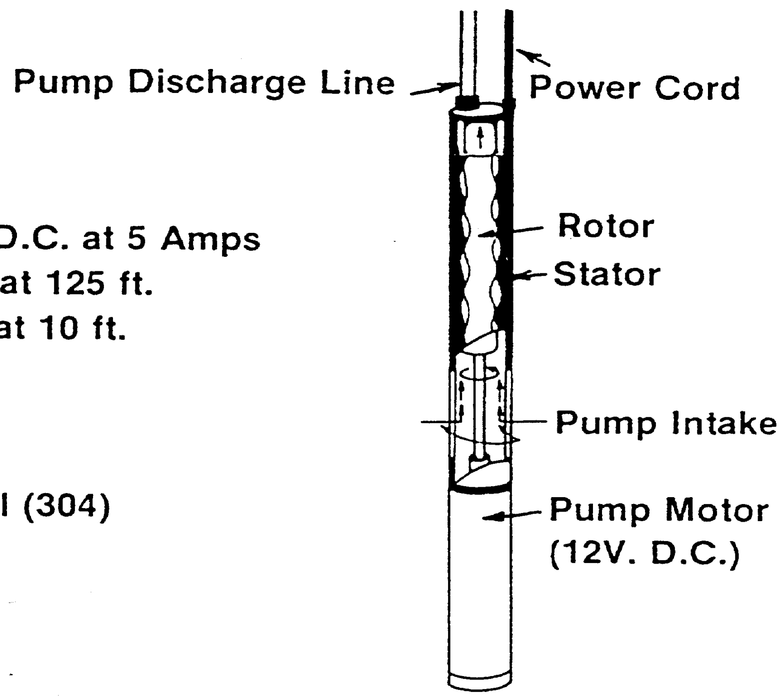
Progressive cavity pumps are categorized as a positive displacement device. They are commonly used for both purging and sampling monitoring wells. These pumps are appropriate for collecting sensitive samples if low-flow pumping rates are used.

Recent studies conducted by Gibs et al., (1994), Imbrigiotta et al., (1988) and Tai et al., (1991) found good precision and recovery of VOCs collected with a helical-rotor pump.

Operation and Materials

Figure 13 illustrates the design and operation of a common progressive cavity pump. An electric pump motor at the base of the pump turns a corkscrew-like helical rotor near the top. The helical rotor causes an upward movement of water trapped in the cavities of the rotor and the water moves up the discharge line. A check valve at the top of the pump ensures that the water in the discharge line (i.e., sample tubing) does not re-enter the pump. A controller box operated at the surface allows for variable pumping rates.

Models are available for use in 2-inch diameter monitoring wells and are made of materials suitable for collecting sensitive samples, such as Teflon® and stainless steel. The



Electrically Operated
Power Source-12 volts D.C. at 5 Amps
Pumping Rate-0.36 PM at 125 ft.
1.26 PM at 10 ft.
Pump Length-19.5"
Pump Diameter-1.75"
Weight-7 lbs.
Materials-Stainless Steel (304)
Teflon
EDPM

Keck® pump is one commercially-available helical-rotor pump capable of achieving low-flow rates and is available for 2-inch monitoring wells.

Advantages of progressive cavity pumps

- When low-flow pumping rates are used, these pumps consistently collect high quality samples.
- Models are available with variable flow rates and low-flow pumping rates.
- Initial high capital cost may be recovered if dedicated pumps are used.
- Models are available that are constructed of relatively inert materials.
- Lift capability is approximately 160 feet (50 meters).
- Allows for easy, direct in-line filtration of samples.

Limitations of progressive cavity pumps

- Pumps not capable of low-flow rates are not suited for collecting gas-sensitive or VOC samples.
- Portable but may be bulky, heavy and difficult to transport over long distances or over rugged terrain.
- Some variable speed models must initially be started at high flow rates.
- Pump may shut-off periodically at low-flow rates (< 200 ml/min).
- Requires external power source, usually a car battery or generator.
- Relatively difficult to disassemble and repair in the field.
- Transport, set-up and decontamination time is high compared to bailers if the pump is not dedicated to the well.
- Limited number of pumps available for 2-inch wells.
- Purging and sampling from deep wells may be slow.
- Rotor and stator may be damaged by turbid or silt-laden water.
- Portable system may freeze up in winter during sampling and decontamination.

2.4.6 Bladder Pumps (gas-operated squeeze or diaphragm pumps)

Bladder pumps are categorized as a positive displacement device. Bladder pumps are commonly used for purging and sampling monitoring wells for a wide variety of parameters, including VOCs and trace metals. They are typically considered among the best devices for collecting samples of VOCs, trace metals and other substances and parameters (Tai et al., 1991; Barcelona et al., 1984; Unwin and Maltby, 1988, Imbriogiotta et al., 1988; and Houghton and Berger, 1984). However, Yeskis et al., (1988) found that the bladder pump was one of the most difficult devices to decontaminate in the field.

Design and Materials

A bladder pump consists of a flexible, squeezable bladder encased in a rigid outer casing. Bladder pumps are designed so that the gas that squeezes the outside of the bladder does not come into contact with the samples. **Figure 14** shows the design of a common bladder pump.

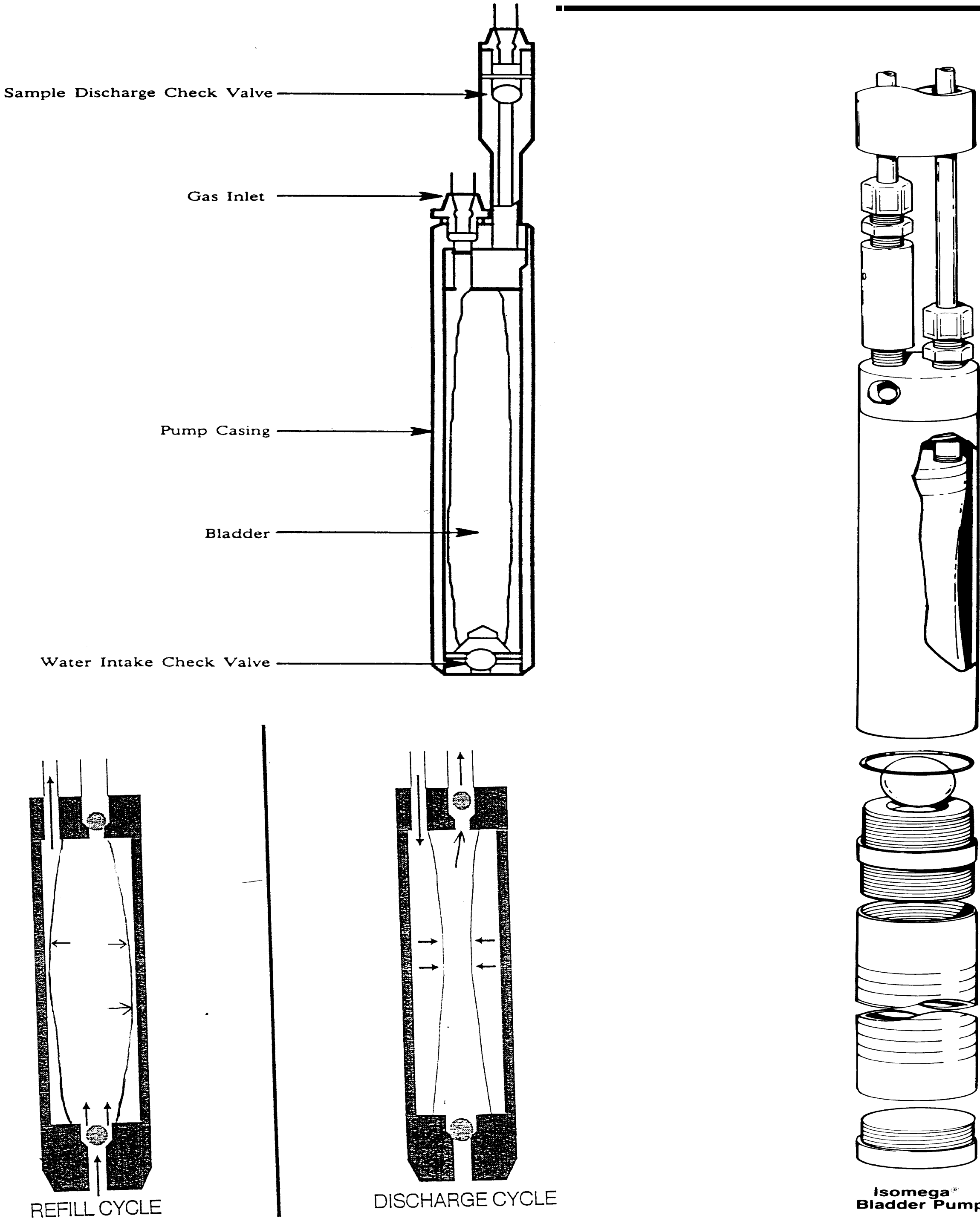


Figure 14: Bladder pump: a) cut-away diagram, upper left (Pohlmann et al., 1990); b) Isomega bladder pump, right (Courtesy of TIMCO™); and c) functional diagram, bottom.

Bladder pumps are commonly constructed of a stainless steel body and a flexible bladder. Bladder pumps are available for 2-inch diameter monitoring wells. As with centrifugal submersible pumps, bladder pumps can be dedicated to above ground wells or flush mount wells (see Figure 12), thus eliminating the need to transport, set-up and decontaminate the pump and collect quality assurance field blank samples.

Operation

A bladder pump operates much like a plastic squeeze bottle that has a liquid in it. Figure 14 illustrates the fill and discharge cycles of a common bladder pump. After you lower the device into the well's water column, water enters the bottom of the bladder under hydrostatic pressure through a check valve at the bottom of the pump. When the bladder is full, a check valve seals its bottom. A controller box at the well surface injects gas into the space between the pump casing and the outside bladder wall, thus squeezing the bladder. This squeezing causes the water to rise out of the bladder and up the sample tubing. When the bladder is nearly empty, the controller box releases the gas pressure and the bladder fills up again with water. A check valve at the top of the pump ensures that the water in the sample tubing does not re-enter the bladder. In some models, the water and air chambers are reversed.

A pneumatic controller box at the surface controls the gas injection and pressure release cycles that drive the pump. The controller box adjusts the purging and sampling flow rates by adjusting the injection and exhaustion cycles of gas in and out of the space between the outer casing and the bladder. The pump's lift capabilities are directly related to the pressure rating of the bladder and tubing and the ability of the pressure source (e.g., air compressor or compressed gas) and controller box to apply a sufficient force of gas at depth.

Advantages of bladder pumps

- When low-flow pumping rates are used, these pumps consistently collect high quality samples.
- Sample does not contact compression gas or mechanical parts of pump.
- Flexible bladder may be constructed of relatively inert materials.
- Capable of variable flow rate and low-flow rates.
- Capable of collecting very low turbidity samples (< 5 NTUs).
- Allows for easy, direct in-line filtration of samples.
- Very high lift capacity (1000 feet or 305 meters for some models).
- Initial high capital cost may be recovered if dedicated pumps are used.
- Pump is not damaged if run dry.
- Easily repaired in the field and very reliable.
- Lends itself to permanent dedication to a well.

Limitations of bladder pumps

- Portable but may be bulky, heavy and difficult to transport long distances or over rugged terrain.
- Requires compressed gas and controller box.
- Purging and sampling from deep wells may be slow.
- Depending on design, may be time consuming to disassemble and decontaminate.

- Bladder may rupture when used in deep wells.
- Portable systems may freeze up in winter during sampling and decontamination.
- Transport, set-up and tear-down time is high compared to bailers if the pump is not dedicated to the well.

2.4.7 Gas-displacement or Air-displacement Pumps (also gas-drive pumps)

Gas-displacement or air-displacement pumps are categorized as a positive displacement device. Gas-displacement pumps (also called air-drive pumps) use a gas other than air (e.g., nitrogen gas) to drive the pump. Air-displacement pumps (or air-drive pumps) use air, typically supplied by an air compressor, to drive the pump. Gas-displacement or air-displacement pumps are more commonly used for purging than sampling monitoring wells. Do not use these pumps for collecting gas-sensitive, redox-sensitive or volatile samples. Do not confuse these devices with gas-lift or air-lift pumps. (Refer to Section 2.4.11.)

Operation and Materials

Figure 15 illustrates the design and operation of gas- or air-displacement pumps. As you lower a gas- or air-displacement pump into the water column, hydrostatic pressure opens an inlet check valve at the bottom and water fills the pump chamber. When the pump chamber is full, the inlet check valve seals itself. Gas or air pressure is applied at the top of the pump chamber and the gas or air pressure displaces the water in the chamber and forces the water up the sample tubing. After the chamber is empty, the gas or air pressure is released and the hydrostatic pressure of the water begins to refill the pump chamber again. A check valve at the top of the pump prevents water from re-entering the pump chamber. Adjusting the pressuring and venting cycles for these devices can be tedious and time consuming and must be redone whenever the depth of the pump is changed.

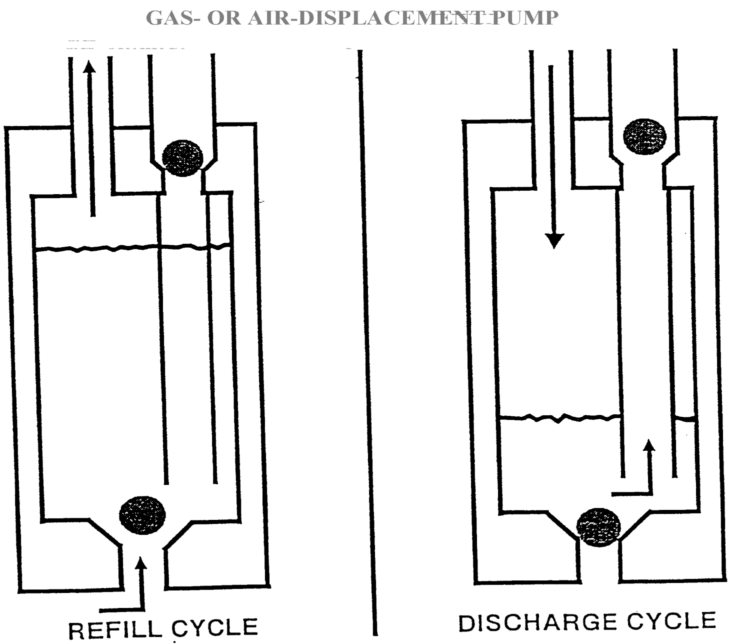
These pumps can be made of inert material to avoid sorption and leaching. These pumps can alter gas-sensitive, redox-sensitive and VOC samples. They may also change the pH of a sample because of increasing or decreasing CO_2 concentrations as gas or air pressure is applied to the water in the pump's chamber. Using an inert gas such as nitrogen (N_2) may minimize sample oxidation and volatilization.

Advantages of gas-displacement or air-displacement pumps

- Very portable and inexpensive.
- Available for wells as small as 1.25 inches in diameter.
- Acceptable for collecting non-sensitive parameters.

Limitations of gas-displacement or air-displacement pumps

- Air-displacement pumps may cause oxidation and volatilization of samples.
- Not very efficient for purging 2-inch diameter or larger wells.
- Require gas or air compressor, or compressed gas or air.
- Can be difficult to disassemble, repair and decontaminate in the field.
- Don't work well in deep wells.
- Pressuring and venting cycles must be adjusted every time pump's depth is changed.



■ May cause changes in the CO_2 and pH of samples.

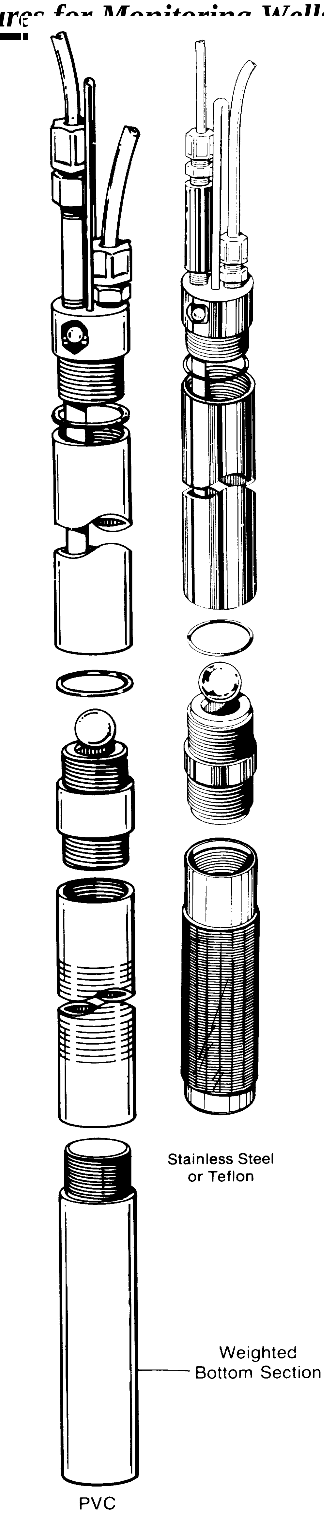


Figure 15: Gas-displacement or air-displacement pump: a) gas or air displacement pump, right (Courtesy of TIMCO™); b) functional diagram, left.

2.4.8 Piston Pumps (manual and gas-drive piston pumps)

Piston pumps are categorized as positive displacement devices. You may use a piston pump to purge and sample monitoring wells depending on their design, materials and mode of operation. Knobel and Mann (1993) and Yeskis et al., (1988) found that the air-operated reciprocating piston pump recovered VOC concentrations comparable to those found using a submersible centrifugal pump and bladder pump. However, a previous study conducted by Nielsen and Yeates (1985) found that the intricate valving mechanism of these pumps, which can cause a series of pressure drops, can lead to pH changes and degassing in the sample.

<u>Operation and Materials</u>

Piston pumps may be mechanical or pneumatic and may have one or more pistons (plungers). The design of most piston pumps consists of a single-direction or dual-direction piston. With the single-direction piston design, as the piston travels up and down the pump chamber, it draws water into the chamber under suction on the up stroke and then forces the water out of the chamber and up the sample tube on the down stroke. With the dual-direction piston design, water is simultaneously sucked in and forced out as the piston(s) is moved in both the up and down direction. **Figure 16** illustrates the design and operation of a dual-direction piston pump.

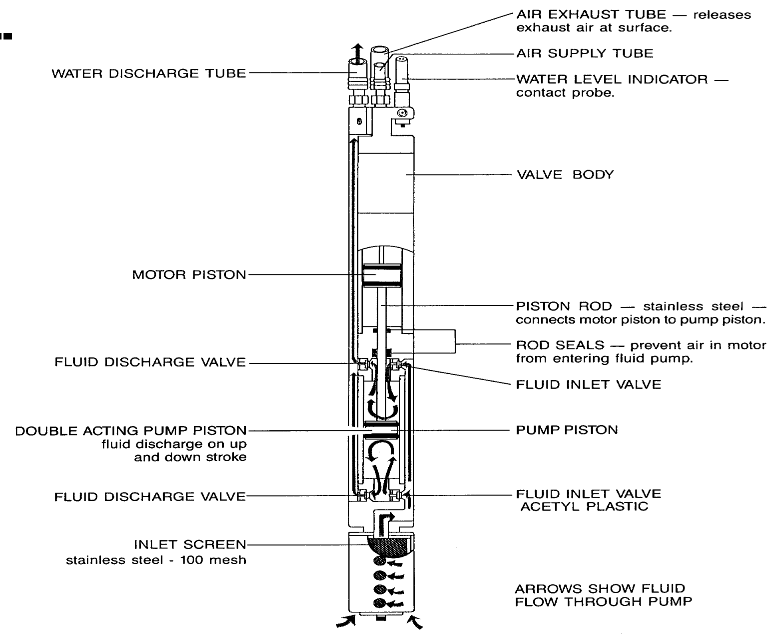
Piston pumps can provide representative samples for non-gas and non-pressure sensitive samples. The action of the piston may create pressure changes on the sample that may cause degassing and changes in sample chemistry; however, if the pump cycling rate is decreased, these affects can be minimized. The piston (plunger) and O-ring seals equipped on most piston pumps may sorb various VOCs that make decontamination of these pumps difficult.

<u>Advantages of piston pumps</u>

- High lift capabilities - 500 feet (150 meters) for mechanical designs and 1000 feet (305 meters) for pneumatic designs.
- Allows for easy, direct in-line filtration of samples.
- Can be constructed of relatively inert materials.
- Models with variable flow rate capabilities are available.
- Moderately easy to operate.
- Models available for 2-inch diameter and smaller wells.

<u>Limitations of piston pumps</u>

- Susceptible to damage, binding or failure in silt-laden and turbid water.
- May be damaged if pump is run dry.
- Requires external power source or pressurized-gas source.
- Difficult to disassemble, repair and decontaminate in the field.
- Equipment is moderately bulky, heavy and not very portable.
- Contact with the pump's mechanisms can cause contamination.
- Moderately expensive to purchase and operate.



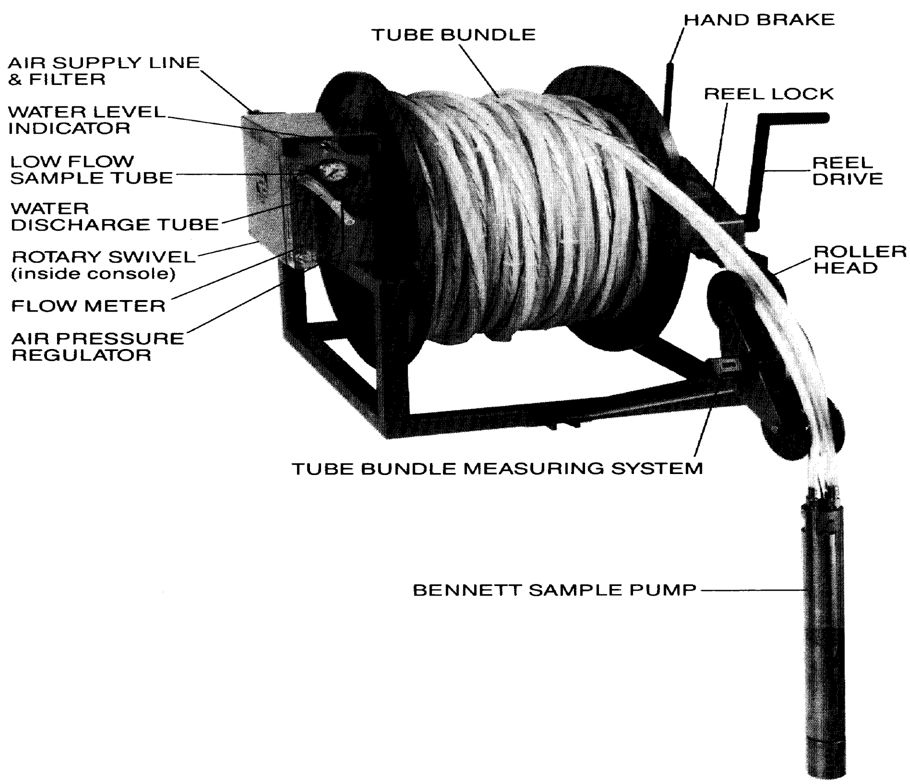


Figure 16: Piston pump: a) automatic reciprocating piston pump, upper left; and b) portable piston pump

system, lower right. (Both diagrams courtesy of Bennet Sample Pumps, Inc.)

2.4.9 Gear-drive Pumps

The gear-drive pump is categorized as a positive displacement device. Historically, gear-drive electrical submersible pumps have not been used for groundwater sampling; however, they do show promise for this purpose because they are very portable and serviceable under field conditions. In theory, these pumps, if operated at low-flow rates, should consistently collect high quality, representative samples; however, research and literature is limited on their abilities and limitations. Imbrigiotta et al. (1988) conducted a field evaluation of seven sampling devices for POCs in groundwater and found that the gear submersible pump had the highest precision and recovery of POC concentrations in comparison to the three other pumps and three grab samplers.

Operation and Materials

Figure 17 illustrates the design and operation of a gear-drive pump. This type of pump operates using a small high-efficiency electric motor that rotates a pair of meshing gears. The meshing gears have teeth that trap and move the water in either a clockwise or counter clockwise direction. Water enters through the bottom of the pump and exits through the top and into the sample tubing.

Flow rates cannot be controlled with conventional gear-drive pumps; however, there are now gear-drive pumps that allow variable flow rates. These pumps are available with either a self-contained power source (typically six hours of operation before recharging is required) or require an external electric power source. The body of gear-drive pumps is commonly constructed of stainless steel and the gears are commonly constructed of PTFE (Teflon®).

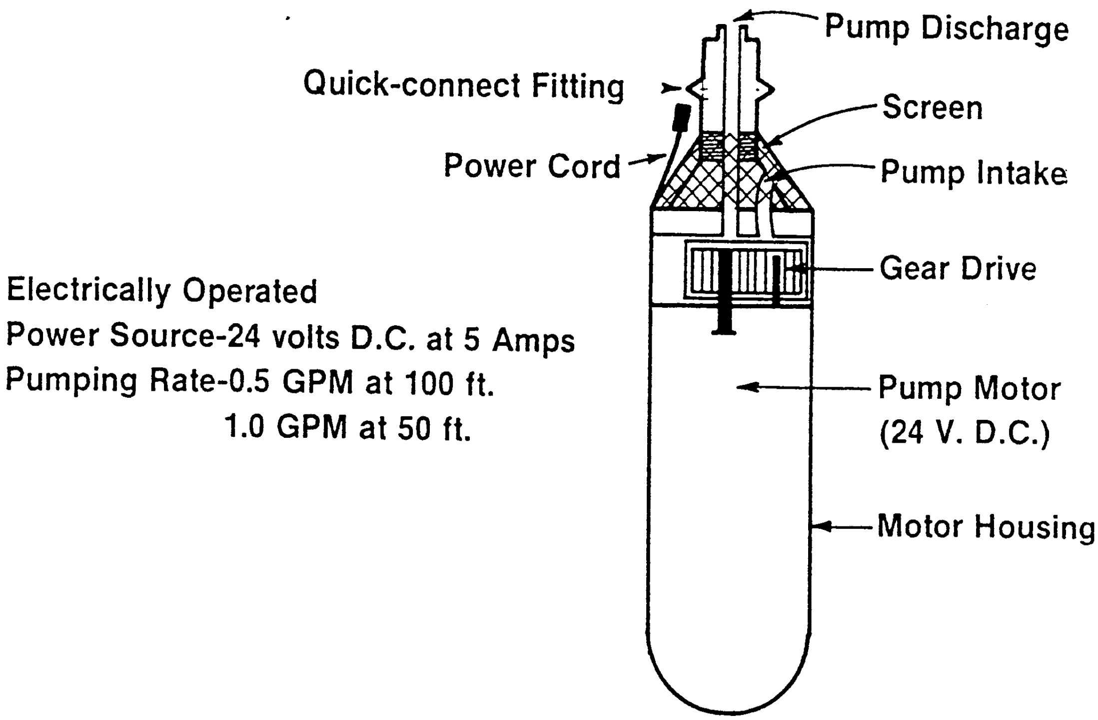
Gear-drive pumps may not be appropriate for purging large volumes of water. If a gear-drive pump is not capable of low-flow rates, it may not be appropriate for collecting sensitive samples.

Advantages of Gear-drive Pumps

- Can be constructed of relatively inert materials.
- Very portable and totally self-contained.
- Easy to operate, disassemble, repair and decontaminate in the field.
- Inexpensive to purchase andoperate.
- Allows for easy, direct in-line filtration of samples.

Limitations of Gear-drive Pumps

- Ability to control flow rate may not be available for some models.
- Silt-laden or turbid water quickly wears down gears.
- Requires a power source.
- Potential for pressure changes in samples due to cavitation from pump gears.
- Some models are not available for 2-inch diameter wells.
- Lift capability of 200 feet (60 meters) or less.


Pump Discharge
Quick-connect Fitting
Screen
Power Cord
Pump Intake
Gear Drive
Electrically Operated
Power Source-24 volts D.C. at 5 Amps
Pumping Rate-0.5 GPM at 100 ft.
1.0 GPM at 50 ft.
Pump Motor
(24 V. D.C.)
Motor Housing

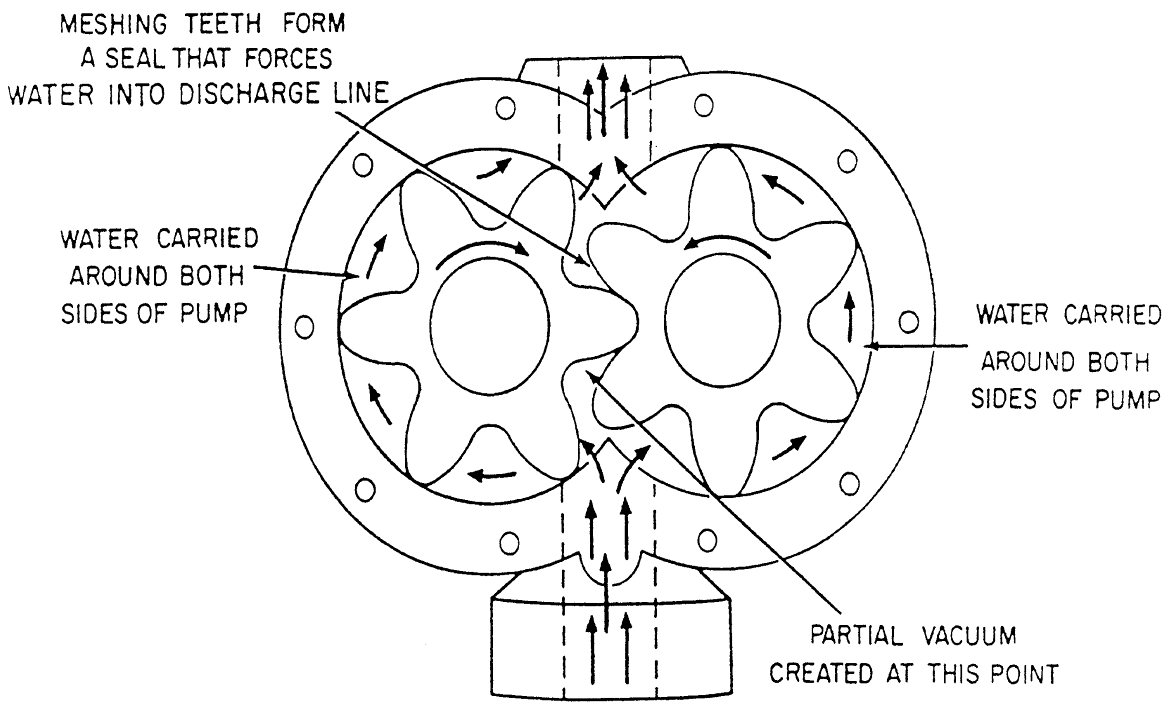

MESHING TEETH FORM
A SEAL THAT FORCES
WATER INTO DISCHARGE LINE
WATER CARRIED
AROUND BOTH
SIDES OF PUMP
WATER CARRIED
AROUND BOTH
SIDES OF PUMP
PARTIAL VACUUM
CREATED AT THIS POINT

Figure 17: Gear-drive pump: a) cut-away diagram, top; and b) functional diagram, bottom.